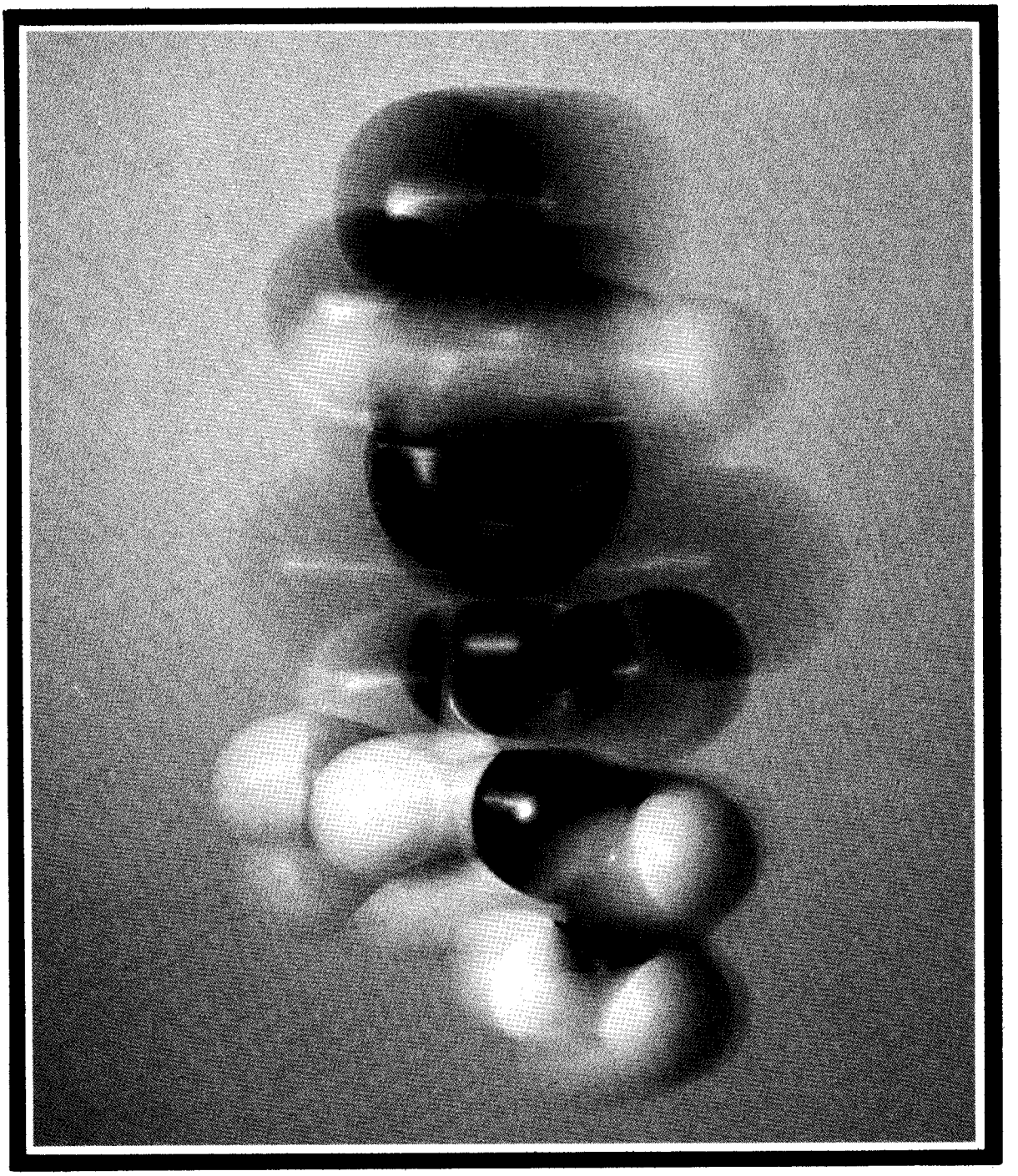
United States
Department of
Agriculture

Southeastern Forest
Experiment Station

Forest Service

Field and Laboratory Evaluations of Insecticides for Southern Pine Beetle Control

General Technical
Report SE-21



CONTENTS

August 1981
Southeastern Forest Experiment Station
Asheville, North Carolina

FIELD AND LABORATORY EVALUATIONS OF INSECTICIDES FOR SOUTHERN PINE BEETLE CONTROL

Edited by
Felton L. Hastings, Project Leader
Forestry Sciences Laboratory
Research Triangle Park, North Carolina

and

Jack E. Coster, Applications Coordinator
Expanded Southern Pine Beetle
Research and Application Program
Pineville, Louisiana

ABSTRACT.—Reports results of laboratory screenings and field studies of insecticides for use against the southern pine beetle. Preventive as well as remedial efficacy were observed, along with phytotoxicity to pine and understory hardwood species, effects of insecticides on soil microbial and mesofaunal populations, and degradation of insecticides by selected soil microbes.
Keywords: *Dendroctonus frontalis*, efficacy, microbial degradation, phytotoxicity, adjuvants, lindane, chlorpyrifos, chlorpyrifos-methyl, fenitrothion.

PREFACE

In 1974 the U.S. Department of Agriculture initiated the Combined Forest Pest Research and Development Program, an interagency effort that concentrated on the Douglas-fir tussock moth in the West, on the gypsy moth in the Northeast, and on the southern pine beetle in the South. The work reported in this publication was funded in whole or in part by the Expanded Southern Pine Beetle Research and Application Program.

Within the Program, a toxicants working group was one of seven such ad hoc groups organized. Each working group consisted of a subject area coordinator and the funded investigators working on projects directly related to the subject area. The groups interacted as needed to discuss approaches, share results, and review progress.

This publication reports on insecticide research undertaken by projects in the toxicants working group between 1974 and October 1980. It is intended as a compendium of such research. Techniques and results reported should be useful to future research on chemical control of pine bark beetles.

Investigators who have contributed to this report are:

C. W. Berisford and U. E. Brady. Department of Entomology, University of Georgia, Athens, Georgia.

G. E. Fitzpatrick, J. H. Lashomb, R. F. Mizell III, and W. W. Neel. Department of Entomology, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi State, Mississippi.

F. L. Hastings, A. S. Jones, and C. K. Franklin. USDA Forest Service, Southeastern Forest Experiment Station, Research Triangle Park, North Carolina.

I. R. Ragenovich. USDA Forest Service, Southwestern Region, Albuquerque, New Mexico.

INTRODUCTION

Outbreaks of southern pine beetle (SPB), *Dendroctonus frontalis* Zimmerman, occur almost every year somewhere in the Southern and Southeastern United States. Although direct chemical control of SPB is often impractical, such control is appropriate in some instances. This is particularly true for high-value trees of parks, yards, campgrounds, seed orchards, and other special-use forest areas.

At the beginning of the Expanded Southern Pine Beetle Research and Application Program, only benzene hexachloride and its gamma isomer, lindane, were registered for the control of SPB. Because of possible environmental and human safety considerations, their continued availability for insect control was under question. An objective of the Southern Pine Beetle Program was, therefore, to register two additional insecticides for use against SPB.

The strategy of the first field season was to test an insecticide that had shown potential against western bark beetles. Concurrently, an extensive screening program began to identify compounds that were highly toxic to the SPB, low in mammalian toxicity, and environmentally acceptable. Based on the screening tests, field tests for determining preventive and remedial efficacy were established in Louisiana, Mississippi, Georgia, and North Carolina. Remedial applications were against established SPB broods in previously attacked trees, while preventive applications were on unattacked pines.

Other studies included: the dissipation of spray residues from pine bark with and without adjuvants, the deposition of insecticidal sprays on pine bark with conventional and antidrift systems; the development of a technique for assessing preventive efficacy; the assessment of insecticidal impacts on forest soil microbial and mesofaunal populations; the degradation of insecticides by selected soil microbes; the phytotoxicity of insecticides toward two pine species and understory flora; the assessment of partial tree-bole sprays for preventing SPB attack.

Some of the studies did not produce results that can be applied in SPB control, but these are included so that future researchers might benefit from them.

SCREENING TESTS

F. L. Hastings, A. S. Jones, C. K. Franklin

TOPICAL TESTS

PROCEDURES

Test insects were obtained from infested bark of loblolly pine, *Pinus taeda* L., growing in the North Carolina Piedmont. Beetles were collected with light traps beneath 0.74 m^3 fiberboard drums containing the infested bark. Conditions in the emergence chambers were maintained at 26° ± 2°C and > 90 percent relative humidity (RH). All compounds were freshly prepared in reagent-grade acetone at concentrations expressed by weight. Each was applied topically as a 0.25-µl droplet to the thorax of adult beetles with a Burkard Arnold Microapplicator and 30-gage needle. Beetles were treated within 4 hours of emergence, placed in a mixture of freshly ground phloem and bark, and held at 20° ± 1°C and 100 percent RH. Control insects were treated with acetone only and held under similar conditions. Each experiment was replicated from three to eight times on different days, and 5 to 11 concentrations of each insecticide were tested. In calculating mortality after 48 hours, moribund insects were considered dead. Dosage-mortality regression curves were computed by standard methods (Daum 1970). Relative potency was calculated based on lindane toxicity.

RESULTS

When the holding chambers were evaluated, more than 90 percent of untreated adult beetles survived through 72 hours. In the experiments, survival of the acetone-treated insects at 48 hours always exceeded 90 percent.

Table 1 shows the topical lethal dose (LD) values. The most toxic compound, the synthetic pyrethroid (permethrin), was 14 times as toxic as lindane at all LD values. The next best, the organophosphate chlorpyrifos-methyl, was 10 times more toxic than the standard lindane. Seventeen insecticides were more toxic than lindane toward this insect at LD_{50}. These results indicate that several insecticides might be effective replacements for lindane and BHC against the SPB.

A number of these 17 compounds were not further tested for the following reasons: (1) The LD_{90} values of methomyl and aminocarb are much higher than that of lindane. (2) Carbofuran is too toxic to mammals. (3) Diazinon does not persist long enough on the bark to be effective (Brady and Berisford 1977). (4) Stirofos will not be manufactured for field use. The compounds tested are listed in the bolt bioassay section.

In two instances where the phosphorylalkoxy substitution was compared, (*O,O*-dimethyl vs. *O,O*-diethyl), the *O,O*-dimethyl substitution resulted in good selectivity ratios, LD_{50} rat:LD_{50} insect (Kenaga and End 1974). Selectivity ratios for pirimiphos-methyl and pirimiphos-ethyl were 229 vs. 16, while for chlorpyrifos-methyl and chlorpyrifos, ratios were 278 vs. 16.

BOLT BIOASSAYS

PROCEDURES

The 12 insecticides that were bioassayed for contact toxicity to SPB included one synthetic pyrethroid (permethrin), 10 organophosphates (chlorpyrifos, chlorpyrifos-methyl, etrimphos, fenitrothion, phosmet, pirimiphos-ethyl, pirimiphos-methyl, carbophenothion, naled, dicrotophos) and one chorinated hydrocarbon (lindane). All compounds were formulated as emulsifiable concentrates (EC). A microencapsulated formulation of phosmet (encap) was also tested.

We selected trees for the bioassay from active SPB spots around the Research Triangle Park area in central North Carolina. They were loblolly pine and shortleaf pine, *P. echinata* Mill., 15 to 30.5 cm d.b.h. with indications of heavy attack over most of the length of the trunk. We chose only trees in which the majority of beetles were late instar larvae or pupae. Field crews felled and cut suitable trees into 0.5-m bolts and numbered them consecutively, beginning at the base of the trunk. A sequential sampling technique using a 5-cm section from each end of each bolt provided an X-ray estimate of beetle density (larvae, pupae, and adults).

Four treatments—2, 1, 0.5, and 0.25 percent concentrations of the test insecticides—were randomly assigned to the bolts. Untreated bolts served as controls. Lindane at 0.5 percent (the registered dosage) served as a standard for comparison of efficacy.

Freshly prepared aqueous insecticide solutions containing 2.0 percent (w/v) active ingredient were applied to the bolts with a Kinkelder® low-volume sprayer calibrated to wet a bolt just to runoff in 40 seconds. To provide uniform spray coverage, the bolts were rotated on a turntable during the application. The concentration range was obtained by spraying the bolts for 40, 20, 10, and 5 seconds to give 2, 1, 0.5, and 0.25 percent concentrations, respectively.

The sprayed bolts were enclosed in cylindrical cages made of No. 32 mesh Saran® screen and hung on frames under a mature loblolly canopy to simulate field conditions. Emerging beetles were collected daily from each bolt and the number of dead and live beetles recorded. Each Tuesday and Wednesday, the live beetles were held in the laboratory for 48 hours and any additional mortality was recorded. The purpose was to assess whether these live beetles represented a threat of further attack.

The experimental design for the remedial bioassay was a completely randomized design with 42 treatments. A general least squares analysis was done for each of the following response variables: (1) percent mortality in the subsample of beetles held for 48 hours after emergence; (2) percent mortality of emerging beetles, corrected for 48 hours mortality; and (3) percent mortality in the bolt.

Duncan's multiple range test was applied to all response variables showing significance in the least squares analysis to rank differences among the treatments. In addition, the relationship between the X-ray estimate of number of beetles in the bolts and the number that actually emerged was examined, and a linear regression fitted: total emerged beetles = a + b (X-ray estimate of number of beetles).

RESULTS

Table 2 presents the results of the least squares analysis. The differences between treatments were highly significant for percent mortality in the subsamples held in the laboratory for 48 hours after collection (PerDed-48). This result confirmed the importance of assessing the longevity of beetles emerging from treated bolts. Duncan's multiple range test was performed to compare treatments (table 3). Mortality ranged from 100 percent for 2 percent chlorpyrifos-methyl to 4 percent for 0.25 percent carbophenothion. The formulation of phosmet (EC) was not significantly different from the control at any concentration, while all four concentrations of chlorpyrifos-methyl, chlorpyrifos, and permethrin were significantly different. The permethrin concentrations were inadvertently cut in half; therefore, the concentrations were 1, 0.5, 0.25, and 0.125 percent. In comparison with the standard (0.5 percent lindane), three treatments–1 percent and 2 percent chlorpyrifos-methyl and 2 percent chlorpyrifos–had significantly higher mortality after 48 hours.

We calculated the percentage mortality of beetles in the bolt (PerDedBo) as follows: the number of beetles in the X-ray estimate minus the total number of beetles which emerged was divided by the X-ray estimate of number of beetles in the bolt. The least squares analysis of this variable showed no significant treatment differences. Duncan's multiple range test indicated that only 2 percent chlorpyrifos-methyl was significantly different from the controls. Interestingly, in the 0.5 percent, 1 percent, and 2 percent phosmet (EC) and 2 percent pirimiphos-ethyl treated bolts, total emergence actually exceeded the X-ray estimate. It is possible that with chlorpyrifos-methyl at the highest concentration, some fumigant action occurred and with phosmet, a flushing action.

A third response variable, percent total mortality (PertDead), was calculated by multiplying the mortality observed for emerging beetles by a correction factor for the additional mortality observed in the subsamples held for 48 hours. Treatment effects were also highly significant for this variable. Table 4 shows Duncan's multiple range test for this variable. The ranking of treatments for this response variable is very complex, with 16 different ranges of significance. Here, 2 percent chlorpyrifos and 2 percent fenitrothion were outstanding, with 95 percent and 94 percent mortality, respectively. Also, there was no significant difference between 0.25 and 0.5 percent carbophenothion and the controls.

Eleven treatments were significantly better than 0.5 percent lindane. They included 1 and 2 percent concentrations of chlorpyrifos-methyl, chlorpyrifos, fenitrothion and etrimphos; and the 2 percent concentrations of pirimiphos-ethyl and the microencapsulated formulation of phosmet. At the 0.5 percent concentration, only chlorpyrifos was significantly better than lindane.

Our results may provide some insight into lindane's erratic performance in SPB suppression efforts in recent outbreaks; the recommended concentration killed an average of only 61 percent of the emerging beetles.

Arc sine transformations were performed on the percent mortality data, but we saw no differences in results of the statistical analysis.

EFFICACY STUDIES: PREVENTION

C. W. Berisford, U. E. Brady, G. E. Fitzpatrick,
C. K. Franklin, F. L. Hastings, A. S. Jones, J. H. Lashomb,
R. F. Mizell III, W. W. Neel, and I. R. Ragenovich

PROCEDURES

Based on results of the screening tests, four insecticides (chlorpyrifos, chlorpyrifos-methyl, fenitrothion, and carbaryl) were further tested to establish their efficacy for both prevention of SPB attacks and remedial control of beetles in infested pines. Efficacy tests were carried out in North Carolina by Hastings, Jones, and Franklin; in Georgia and South Carolina by Berisford and Brady; in Mississippi by Mizell, Lashomb, Fitzpatrick, and Neel; Berisford and Brady; and in Louisiana by Ragenovich.

Aqueous sprays of 0.5 percent lindane were the standard, or reference, in all efficacy tests. All test insecticides were mixed as aqueous sprays. Oil sprays were excluded because of their possible phytotoxic effects, their expense in operational conditions, and the relative ease in mixing waterbase sprays in remote field locations.

The relative effectiveness of insecticides in preventing SPB attack was estimated in three types of experiments: (1) forced-attacked tests, (2) hanging-bolt tests, and (3) standing-tree tests. Uninfested, standing loblolly or shortleaf pines were thoroughly sprayed with hydraulic sprayers operated at 200 to 300 lb/in^2. Depending on the type of test, bolts were either cut from felled trees or the trees were left standing.

Forced-attack tests were used by Hastings and others in North Carolina with chlorpyrifos-methyl and by Berisford and Brady in Georgia with chlorpyrifos and chlorpyrifos-methyl. Field-sprayed bolts of 0.5-m length were taken to the lab where their cut ends were coated with paraffin to reduce moisture loss. Five pairs of newly emerged SPB adults were confined on each test bolt by No. 32 mesh Saran screen. After 25 days the bolts were peeled and the number of successful attacks, the number of live and dead beetles, and the lengths of egg galleries were recorded.

In hanging-bolt tests, 1.5- to 2-m-long bolts were cut from the field-sprayed trees and taken to sites adjacent to natural infestations of SPB (Berisford and others 1980). The bolts were attached to uninfested trees and hung at about 3 m above the ground. One or two bolts per tree were used. A 20- by 50-cm (1,000 cm^2) wire-screen sticky trap was fastened to each bolt to monitor SPB visitation. Each bolt was also baited with frontalure (a 1:2 mixture of frontalin and α-pinene) to invite attack. Frontalure was released from 2-dr vial caps or from cigarette filters (Gammill and others 1978). After 25 to 30 days, workers removed the bolts and recorded numbers of SPB trapped on screens. They also delineated a 1,000-cm^2 area opposite the sticky trap, peeled the bark, and recorded numbers of SPB attacks and total lengths of egg galleries. Hanging-bolt tests were done with all four insecticides in each of the five States.

The survival, or death, of living sprayed trees is the ultimate criterion of prevention of SPB attack. Standing-tree bioassays were used with chlorpyrifos and chlorpyrifos-methyl in Mississippi. Treatment trees were selected near SPB infestations that had at least 25 currently infested trees larger than 15 cm d.b.h. and no less than 23 m^2/ha of pine basal area. The treatment trees were within 100 m of the actively infested trees, and there were green unattacked

pines between the infestations and the treated trees. The unattacked trees served as a reservoir to maintain the SPB infestation for the duration of the test.

Standing unattacked treatment trees were sprayed to the point of runoff. Spray was applied to the boles of the trees up to a height just above the lowest major live limbs (usually 9 to 12 m above the ground). Unsprayed check trees were designated. Both loblolly and shortleaf pines were used as treatment and check trees. A sticky trap similar to those used in the hanging-bolt tests was immediately placed on each study tree at 3 to 3.5 m above the ground. Frontalure release devices were attached to each trap to attract SPB. The traps were inspected and the attractant replenished every 2 to 3 weeks. Crown color, presence of pitch tubes, and proximity to newly attacked trees were recorded for each tree.

RESULTS

North Carolina.—Figure 1 presents field bioassay data comparing chlorpyrifos-methyl at 0.5 and 1 percent to the standard, 0.5 percent lindane. In general, neither concentration of chlorpyrifos-methyl appeared to be a reasonable replacement for lindane as a preventive treatment. The 0.5 percent concentration was comparable to lindane during the first 2 months, whereas the 1 percent concentration was only comparable during the first month. During the third and fourth months, neither concentration of chlorpyrifos-methyl was effective, but after 5 months, both concentrations, as well as lindane, significantly reduced gallery length ($P < 0.05$). In the sixth month, 0.5 percent chlorpyrifos-methyl and lindane were significantly better than either the controls or 1 percent chlorpyrifos-methyl. Beetle activity in the area then declined, and no further testing was possible until 15 months later. At this point, only lindane continued to show activity against the SPB (gallery length significantly reduced as compared to control and chlorpyrifos-methyl treatments ($P < 0.05$).

The laboratory "forced-attack" data (table 5) may explain, in part, the erratic field results. In particular, the two 1 percent chlorpyrifos-methyl bolts for month 2, which had galleries totaling 280 cm, were from the same trees as the two field bioassay bolts that had 3,208 cm, or 71 percent of the galleries. These figures suggest that these trees were

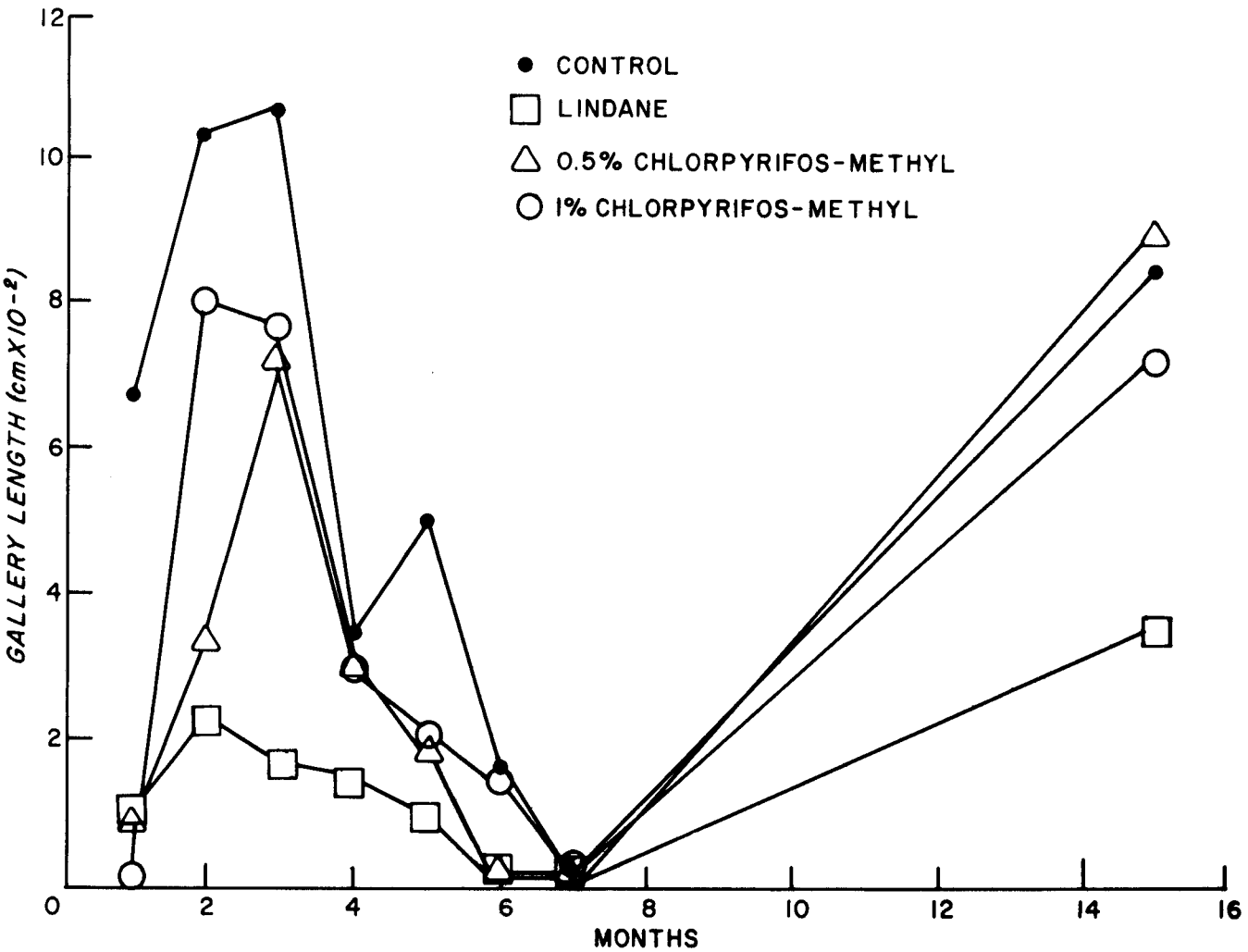


Figure 1.—Time-course experiment comparing the reduction in SPB gallery length with treatment.

not sprayed at all. Throughout the experiment, attack was heavier on the bolts sprayed with 1 percent, suggesting that spray coverage in this plot may have been erratic. The poor performance of the 1 percent chlorpyrifos-methyl in the field test but not in the lab during months 2 and 3 may have been caused by rain removing the insecticide from the field bolts. The area in which the bolts were hung received 12.2 and 11.2 cm of rain during these 2 months. Brady and Berisford[1] have found that chlorpyrifos-methyl can be washed off trees by simulated rainfall even after the spray has dried.

Georgia.—Tables 6 and 7 show that bolts treated with 1 percent fenitrothion had a few SPB attacks and some egg gallery construction at 0-day and a significant number of attacks and gallery length at 2 months. Bolts treated with 2 percent fenitrothion had some attacks but no successful gallery construction until the 4-month bioassay. Attacks and gallery construction of 2 percent fenitrothion at 4 and 6 months indicate that it is probably not an effective preventive control beyond 3 months where SPB pressure is high. Few attacks and no gallery construction occurred on bolts treated with 0.5 percent lindane.

Preliminary tests with two formulations of carbaryl showed that 2 percent Sevimol 4® and UCSF-2 were ineffective at 0-day (tables 6 and 7). Carbaryl was not effective in preventing attack with bark residues of over 3,500 p/m in 0-day bioassays (table 8).

Residue levels through 4 months (table 8) show that fenitrothion may be ineffective if bark residues are below 3,500 p/m. Very low concentrations of lindane residues, however, continue to prevent successful gallery construction (tables 6,7,8).

Table 9 shows the number of SPB caught on sticky traps attached to the chlorpyrifos, chlorpyrifos-methyl, and lindane-treated standing trees. Sites 2 and 3 received moderate pressure during the first 2 months. On site 1 only small, but consistent, numbers of beetles were attracted to the trees. Because no one has determined the number of SPB required to successfully attack and kill a tree, we do not know if enough beetles were present to kill trees on any of the treatments in this spot. However, some untreated trees not included in the test were killed during the study.

All untreated controls in site 2 had died by 16 weeks after treatment, and one tree treated with 1 percent chlorpyrifos-methyl also died. This spot expanded rapidly, and the active front moved away from the treated trees by 26 weeks.

SPB activity ceased at site 3 within 42 weeks. Three untreated controls died by 24 weeks, and all died by 34 weeks after treatment. No trees that had been treated with an insecticide, at any rate, died in this spot.

Table 10 gives bark residues for the four collection dates. Residues for both lindane and chlorpyrifos were similar to those found in previous studies. About 25 percent of the residue at 0-day remained after 12 months.

Although most treatments protected treated trees, the results should be evaluated cautiously. The relatively small numbers of SPB on sticky traps and the general decline of beetles in the area indicated light attack on most trees. Large numbers of SPB and heavy mass attacks might have successfully overwhelmed the insecticide barrier. These results should not be extrapolated to an epidemic situation.

Mississippi.—Twelve Mississippi study sites were evaluated at regular intervals for up to 1 year after trees were treated with chlorpyrifos and chlorpyrifos-methyl. Two of the sites did not have sufficient SBP activity to kill control trees and, therefore, were deleted from further analyses.

Cumulative means of numbers of SPB trapped per tree on each site during the period after spraying are given in figure 2. Variation among sites was very high. For instance, at 30 days, the mean number of SPB trapped per tree ranged from 10 at site 5 to several hundred at sites 1, 10, 11, and 12. The high numbers of active trees and SPB trapped during the study indicate that the experiments rigorously tested the treatments.

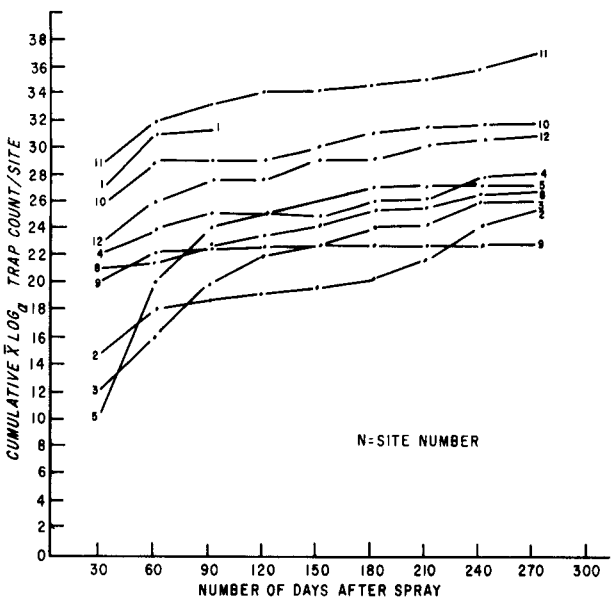


Figure 2.—Cumulative mean number of SPB relative to number of days after treatment.

The presence of pitch tubes on trees usually indicates successful SPB attack. In this study, however, pitch tubes on trees protected by insecticides were not reliable indicators of tree mortality. Figure 3 shows that within 60 days all control trees had pitch tubes; all of these trees died. By contrast, pitch tubes continued to increase in treated trees (70 percent or more had pitch tubes at test termination), but fewer than 58 percent were killed.

The true measure of insecticide efficacy against SPB is prevention of tree mortality. Tree mortality is indicated by a change in crown (needles) color from green to yellow or red. Evaluation of insecticidal performance was based on

[1] Brady, U. E., and C. W. Berisford. 1977. Insecticidal protection of high value pines against the southern pine beetle and other beetles. Expanded Southern Pine Beetle Research and Application Program final report. 18 p. [Personal communication.]

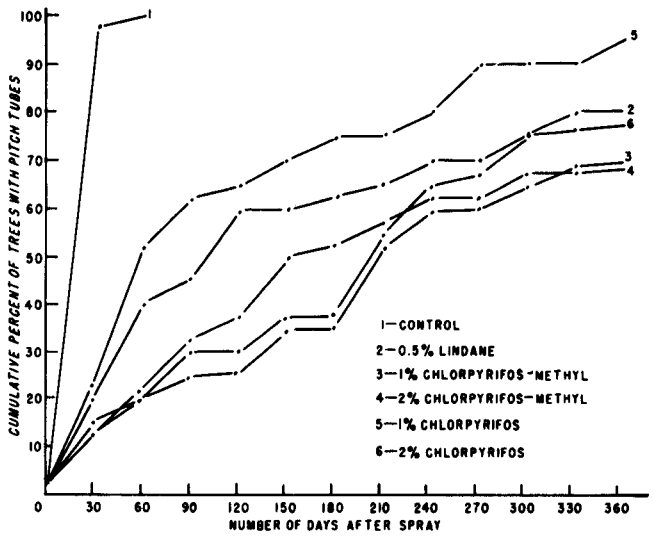


Figure 3.—Occurrence of pitch tubes on trees after six insecticide treatments.

the mean number of days after treatment (control vs. treatment trees) that crown-color change was noted in the trees that died.

Mortality of trees treated with insecticide and control trees occurred continuously during the test period. The variation in time to tree death and crown-color change can be attributed to number and time of beetle mass attack by site, season of the year, individual tree differences, site differences, and interaction of these factors. The important point, however, is that the treatment trees on the average lived longer than did the controls under similar conditions.

Table 11 gives the mean number of days to crown-color change and the number of trees killed in each treatment. All control trees in each of the 10 plots succumbed at a mean 81 days after treatment. The mean time to crown-color change was significantly longer for trees in all insecticide treatments. The failure of this measure to differentiate between insecticidal concentrations suggests that crown-color change may not be precise enough to effectively evaluate insecticidal performance. In studies where number of successful attacks and egg-gallery lengths were measured, the effects of different insecticidal concentrations were discernible (tables 12 and 13).

Table 12 gives results of another series of field efficacy tests of chlorpyrifos and chlorpyrifos-methyl on standing trees in Georgia. Numbers of successful attacks and SPB egg-gallery lengths show that 1 percent and 2 percent chlorpyrifos and chlorpyrifos-methyl were generally as efficacious as 0.5 percent lindane up to 4 months after treatment. At 8, 10, 12, and 15 months after treatment, 1 percent chlorpyrifos was less effective than other candidate formulations. Lindane (0.5 percent) was superior to all other materials 12 and 15 months after application. The time during which lindane is effective in preventing SPB attacks is similar to the protection provided for other species of pine bark beetles (Berisford and Brady 1976; Smith 1970). Overall, chlorpyrifos-methyl tended to provide slightly more protection than chlorpyrifos.

Table 13 gives results of forced-attack tests. Conclusions drawn from these data are similar to those from the field bioassays. Based on number of successful attacks and length of egg galleries 6 and 12 months after treatment, 2 percent chlorpyrifos was generally more effective than 1 percent chlorpyrifos or 0.5 percent lindane. Laboratory bioassays were deemed unnecessary in 1976 due to the success of field bioassays in prior tests and the agreement of results with both bioassay techniques.

In another series of Mississippi tests, the standing-tree method was used to test fenitrothion. For this test, three types of information are presented: (1) time of occurrence of pitch tubes on the treated trees, (2) the mortality of trees in each of the treatments through time, and (3) trap counts through time as a measure of beetle occurrence on the treated trees.

The standing-tree prevention test is highly conservative because treated trees were constantly baited with SPB pheromone, and beetles came to the trees continuously. Thus, a tree was never allowed to fully recover from previous SPB attacks. This situation would not occur in a natural stand where SPB attack en masse over a brief period.

Occurrence of pitch tubes (fig. 4) can be considered a helpful early predictor of the efficacy of an insecticide treatment. Pitch tubes developed immediately on the control trees; 100 percent had pitch tubes 2 months after treatment. Pitch tubes occurred later on treated trees, appearing first on those receiving 1 percent fenitrothion and later on those receiving 2 percent fenitrothion or lindane. By 6 months after treatment, all the treated trees had pitch tubes. In view of this time data, it was assumed that more of the control trees and 1 percent fenitrothion-treated trees would be killed and that these trees would die sooner than

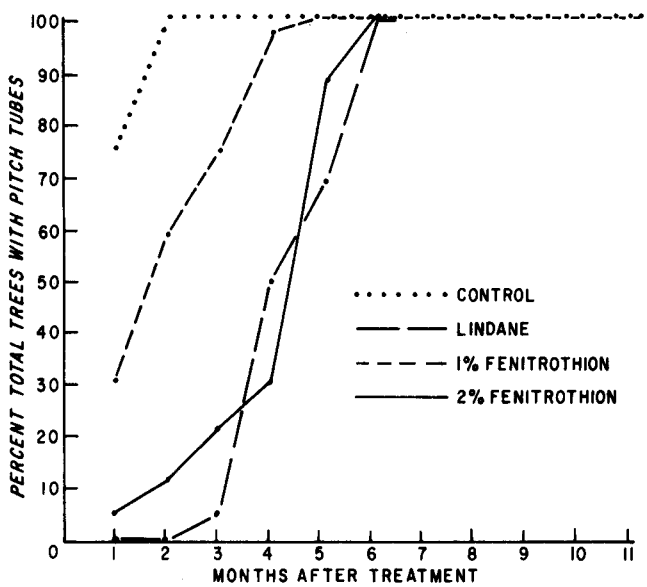


Figure 4.—Time-course of pitch-tube formation following application of lindane and fenitrothion to standing trees in Mississippi.

trees receiving 2 percent fenitrothion or lindane. This assumption was correct.

Figure 5 shows the time of death and percentage of trees in each treatment that were killed during the test. Of the 32 control trees, 84 percent were killed during the test (100 percent if the two sites with lowest beetle pressure are disregarded); 75 percent of these were dead after 3 months. Only 9 percent of the trees receiving the 1 percent fenitrothion treatment had died 5 months after treatment. Most were killed more than 7 months after treatment, though only 34 percent died in all. Lindane and 2 percent fenitrothion were much more effective against SPB. Only 3 percent (one tree each) of the 2 percent fenitrothion and lindane-treated trees were killed in the test, and both died more than 8 months after treatment.

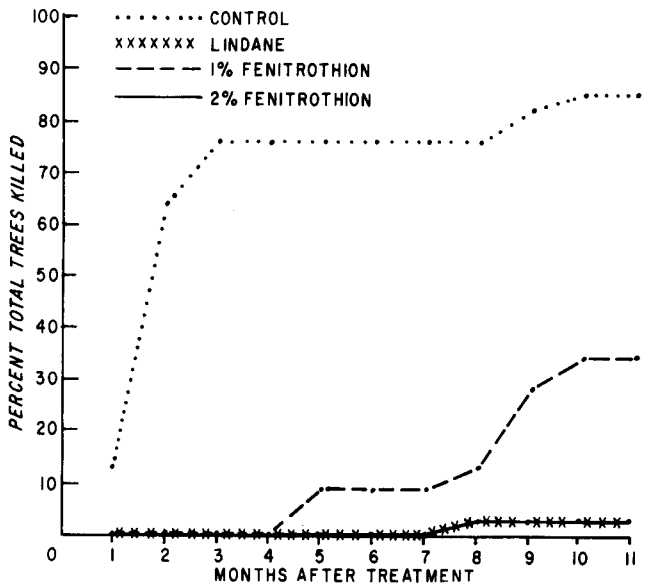


Figure 5.—Time-course of tree mortality following application of lindane and fenitrothion in Mississippi.

It should be pointed out that the eight test sites were sprayed from early May to early June 1978. Thus, from 6 to 7 months after treatment, cold winter weather occurred in Mississippi, slowing SPB activity and probably prolonging the life of some of the 1 percent fenitrothion-treated trees. However, prevention of attack from SPB for 6 months would cover the normal peak period of SPB activity in the Southeastern United States.

To determine how long insecticide protection lasted, we studied the mean number of beetles trapped (± standard deviation) from the time of treatment to the death of the tree or the end of the test (table 14). The counts suggest that the beetle populations at six of eight sites were high enough to test the efficacy of the insecticide treatments. Since not all control trees were killed at two of the sites (14, 20), these sites were eliminated from the analysis.

Variation between sites and among trees within sites was large (table 14). Mean trap counts of the trees in each of the four treatments show that control trees were killed by lower numbers of beetles on the average than were required to kill trees receiving the 1 percent fenitrothion treatment. More importantly, the numbers of beetles that killed the control trees early did not kill the treatment trees: the controls lasted only 2 months, while no 1 percent fenitrothion-treated trees were killed until 5 months after treatment. Because treated trees were constantly baited and subjected to continuous attack, it can be concluded that 1 percent fenitrothion protects trees for up to 4 months and that 2 percent fenitrothion and 0.5 percent lindane give protection for up to 10 months.

The hanging-bolt method was also used to test fenitrothion in Mississippi. Results were comparable to those from the standing-tree method. Numbers of SPB on the bolt traps were similar to those on the standing-tree traps (table 15), indicating that the treatment bolts were exposed to high populations of attacking SPB.

The number of successful attacks per bolt and centimeters gallery construction in each of the treatments varied with time after treatment. Soon after the first month after treatment, trees receiving 1 percent and 2 percent fenitrothion, and lindane, had significantly lower numbers of attacks and centimeters of gallery than the controls.

At 4 months after treatment, the number of successful attacks was not significantly different between controls and trees receiving 1 percent fenitrothion ($P < 0.05$). Values were significantly lower ($P < 0.05$) for trees receiving 2 percent fenitrothion and lindane. Gallery construction after 4 months was significantly lower ($P < 0.05$) in all treated trees than in the controls. Gallery construction in the bolts treated with 1 percent fenitrothion was higher than in bolts treated with 2 percent fenitrothion and lindane.

Results 10 months after treatment were similar to the 4-month results for the 1 percent fenitrothion treatment. After 10 months, the 2 percent fenitrothion and lindane treatments failed to prevent SPB attack but were still significantly better ($P < 0.5$) than controls.

Louisiana.—The hanging-bolt method was used in Louisiana to determine the ability of chlorpyrifos to prevent SPB attack. Sets of bolts were treated and weathered for multiples of 30 days before exposure to beetles. Thus, it was possible to determine how soon treatments became ineffective. Attack was measured by two methods. First, while the bolts were hanging on the trees, the numbers of attacks, as evidenced by entrance holes and boring dust, were counted weekly. These data were used to determine the length of time the treatments prevented beetles from attacking. Second, bark was peeled from a section and gallery lengths were measured. Gallery length was an indicator of successful beetle attack.

Two-factor ANOVA (treatment vs. time; treatment vs. site) were conducted. Three measured variables—trap catch, attacks on bolts, and gallery length—were considered in the analyses. Trap catch was used to determine the presence of SPB. Attack and gallery length were measures of treatment

effect. Treatment significantly affected all variables in the two-factor ANOVA.

Numbers of beetles trapped varied significantly over time, but the lack of significant interactions of the variables suggests that trap catches were associated with changes in population densities over time, and not with time since treatment. In other words, equal numbers of beetles were available to attack each treatment at any given time.

In the ANOVA for treatment vs. time, there was a significant interaction for the adjusted attack variable. This interaction implies a change in the effectiveness of the treatments over time.

The effects of treatments over time (one-way ANOVA) revealed no significant differences between lindane and 1 and 2 percent chlorpyrifos in prevention of attack for up to 3 months (fig. 6). After 3 months there was no significant difference between treatments in preventing attack. The 0.5 percent chlorpyrifos treatment prevented attack for the first month only.

In terms of gallery length, lindane and 1 and 2 percent chlorpyrifos provided protection for the 7 months of the test (fig. 6). The 0.5 percent chlorpyrifos prevented gallery construction for 3 months.

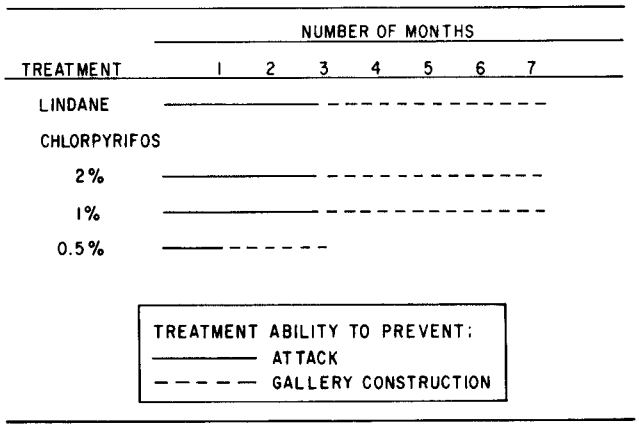


Figure 6.—Length-of-time treatments prevented SPB attack and gallery construction.

EFFICACY STUDIES: REMEDIAL

C. W. Berisford, U. E. Brady, G. E. Fitzpatrick, J. H. Lashomb,
R. F. Mizell III, W. W. Neel, and I. R. Ragenovich

PROCEDURES

The same four insecticides that were tested for prevention were also field-tested for their remedial effectiveness against SPB populations in attacked trees. Aqueous sprays were used in all remedial tests.

Remedial tests were designed to test the efficacy of the four test compounds for killing larvae, pupae, and adults of SPB within trees. Bolts were cut from naturally infested loblolly and shortleaf pines in Louisiana, Georgia, South Carolina, and Mississippi. The d.b.h. of sample infested trees ranged from 15 to 24 cm, and trees contained predominantly late-stage larvae, pupae, and/or brood adults. Three bolts were cut from each tree: one from the lower, one from the middle, and one from the upper one-third of the infested bole. The bolts were initially cut to 1-m lengths. Bark samples were removed from the ends of the bolts, then the bolts were trimmed to ½-m lengths. Beetle numbers in the bark samples were estimated by hand dissection or by use of radiographs.

All three bolts from a tree were given the same treatment. In Georgia, the standing infested trees were sprayed with a hydraulic sprayer; in all other remedial tests, the bolts were sprayed after being cut from the trees. The sprayed bolts were placed in Saran screen rearing bags or ventilated rearing cans (Berisford and others 1976). Emergent beetles were collected and counted periodically over a span of 30 days. In some studies, live emergent beetles were placed in paper ice-cream cartons that contained moist toweling and coarse sawdust. Survival of these beetles was recorded at 12-hour intervals for 72 hours.

RESULTS

Georgia and South Carolina.—Table 16 shows the results of remedial control assays in Georgia and South Carolina. In terms of dead larvae, pupae and adult in treated trees 5 days after spraying and numbers of adults emerging, 0.5 percent chlorpyrifos was less effective than 0.5 percent lindane for remedial control. The 1 percent and 2 percent chlorpyrifos were about as effective as 0.5 percent lindane.

In two different tests in Georgia (table 17), 1 and 2 percent fenitrothion reduced emergence of SPB from treated bolts, and mortality of emerging adults was high for both concentrations. A maximum of 18 percent of emerging adults survived for 72 hours with 1 percent fenitrothion. Lindane reduced emergence of SPB, but a higher percentage of emerging beetles survived for 72 hours. It appears that 1 percent and 2 percent fenitrothion are superior to 0.5 percent lindane for remedial control (fig. 7).

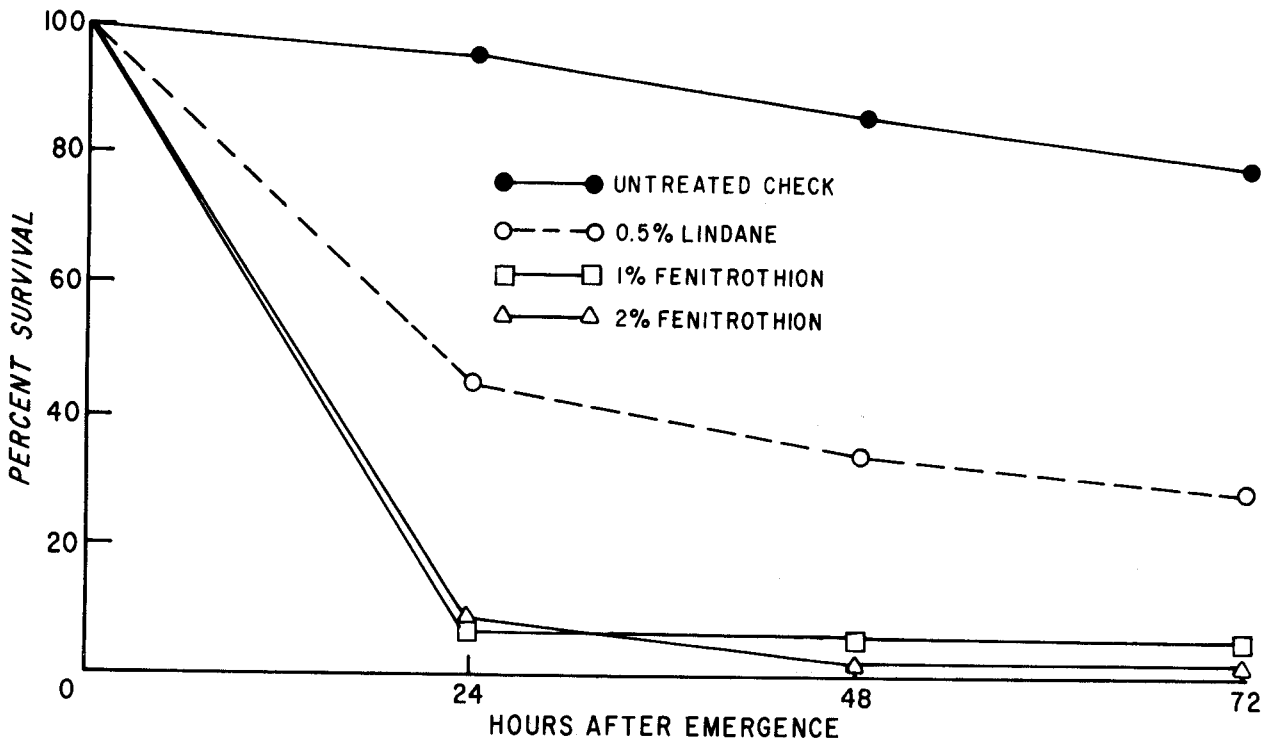


Figure 7.—Comparison of remedial control of SPB by fenitrothion and lindane in Georgia.

Mississippi.–SPB emergence from bolts treated with fenitrothion and lindane varied greatly (table 18). In terms of survival, the 1 and 2 percent fenitrothion treatments performed as well as lindane, if not better. Lindane was shown by Bennett and Pickard (1966) and Jump and Tsao (1973) to be effective as a remedial treatment for SPB. In all three treatments, survival percentages were much lower than in the untreated trees. It should be pointed out that mortality data and beetle emergence were monitored once every 24 hours. Therefore, a 24-hour error could exist in the actual length of beetle survival after emergence.

As a remedial treatment, 1 and 2 percent fenitrothion were equally effective and as good as, if not better than, lindane in killing emerging beetles.

Louisiana.–Treatments significantly affected emergence at the 0.05 confidence level. No other effects were statistically significant. Table 19 shows the total number of beetles emerging from the treatment bolts and the average number of emerging beetles/0.09 m^2 (1 ft^2) of bark surface. Difference between means for each of the chlorpyrifos treatments, and the control and lindane were subjected to *t*-tests. The two chlorpyrifos treatments were not compared. Both concentrations of chlorpyrifos were better than the control, and the chlorpyrifos treatments were as effective as lindane. Duncan's multiple range tests confirmed this result. Figure 8 shows the average number of emerging beetles/0.09 m^2 of bark surface for each replication. Lindane and 1 and 2 percent chlorpyrifos consistently reduced numbers of emerging bark beetles. Although statistical tests did not show that the 0.5 percent concentration of chlorpyrifos was significantly poorer than higher concentrations, the graph suggests that the lower concentration gives less consistent control.

The arc sine transformation showed that all treatments reduced the proportion of the initial brood that emerged per unit area of bark surface. The strength of this test is limited by several factors associated with the X-rays. Timing of the X-rays or dead brood may result in a less than accurate picture of the initial beetle population. However, the estimated average number of brood per unit area and the average number of emerging beetles per unit area for each treatment can be combined to estimate percentage of emergence.

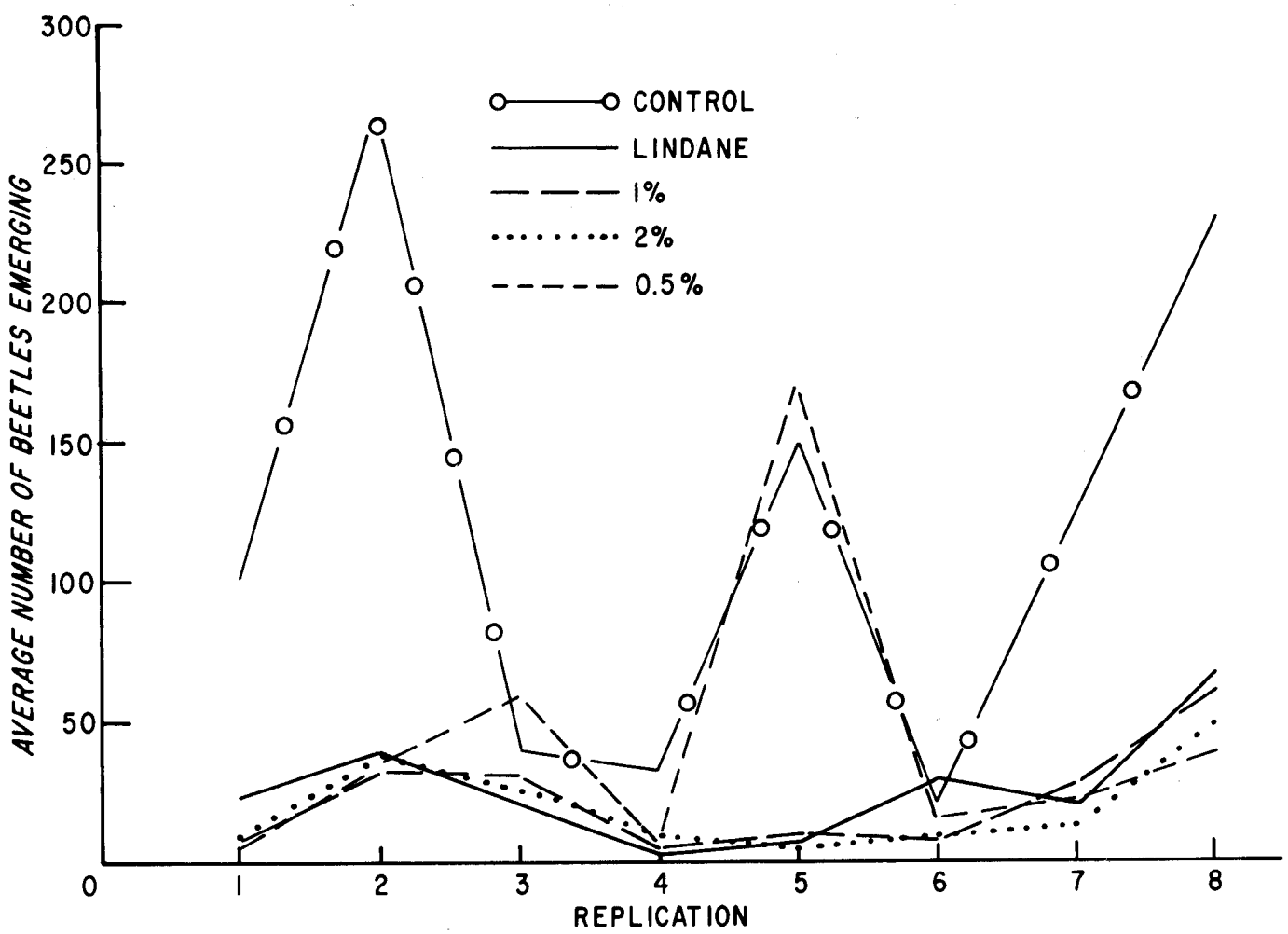


Figure 8.–Average number of SPB emerging/ft^2 of bark surface from bolts treated with chlorpyrifos for remedial control, Louisiana.

RESIDUE STUDIES

C. W. Berisford, U. E. Brady, and I. R. Ragenovich

PROCEDURES

Persistence of insecticide on bark was determined by gas liquid chromatographic (GLC) analysis. Samples of approximately 100 g (ca. 50 cm^2) of the outer 1.27 cm of bark were removed and stored at -20° C until prepared for analysis. Samples were taken 1 to 2 m above ground in standing trees and from the lower, middle, and upper bole of fallen trees.

Samples were chopped in a Hobart food chopper, and two 5-g subsamples were leached for 24 hours in 40 ml of solvent (hexane for lindane and ethyl acetate for chlorpyrifos, chloripyrifos-methyl and fenitrothion). Extraction efficiency of leaching was 95 percent and was comparable to that of blender maceration in replicated tests. Aliquots of each of these extracts were dried with Na_2SO_4 and analyzed by GLC as follows:

Lindane.–Electron capture detector; oven, 210°C; 6-ft glass column packed with 1.5 percent OV-17 and 1.95 percent QF-1 on Chromasorb W.

Chlorpyrifos, chlorpyrifos-methyl, and fenitrothion.–Flame photometric detector, P mode; oven, 190°C, column, 1-ft glass, packed with 5 percent DC-200 on Chromasorb Q.

Carbaryl.–Electron capture detector; column, 145° to 150°C; detector, 225°C; inlet, 170°C; 0.3-m by 4-mm glass column packed with Chromasorb Q 80 to 100 mesh support coated with 3 percent Silicone SE-30; carrier gas flow (N_2), 120 ml/min.

Losses of lindane and chlorpyrifos-methyl from bark following simulated rain were also estimated. Insecticides were applied (three replications) by compressed-air hand sprayers. Table 20 indicates elapsed time between insecticide application and simulated rain (manual sprinkling) as well as volume of water applied per ft^2 (0.09 m^2) of bark. Bark samples were removed 1 hour after the "rain" and analyzed for insecticide content according to procedures described previously.

The effects of adjuvants on deposition and persistence of bark sprays were also determined. Adjuvants, marketed as sticking agents, and antidrift additives were applied to standing loblolly pines as recommended by the manufacturer with 0.5 percent lindane and 1 percent chlorpyrifos. Low-drift spray systems tested were from Delavan Manufacturing Co. and Velsicol Chemical Co. (Accutrol® spray system).

For quantitative evaluation of spray drift, four experiments were conducted in an open field upwind from a rectangular grid system composed of 48 numbered sample collection stations on stakes spaced 5 m apart (length: 8 stations; width: 6 stations). In each experiment the spray gun of each system was stationed 5 m upwind at varying positions, depending on wind direction, along the first row of a six-station side of the grid. Spray containing 0.5 percent lindane wettable powder (WP) and an appropriate amount of the dye to ensure visibility of spray on the collection cards was directed upward and almost perpendicular to the field surface, while a predetermined equal volume of spray was dispensed from each gun. Kromekote cards and cards for GLC analysis of lindane were collected at each sampling station after spray application for subsequent drift analysis. For quantitative evaluation of toxicant deposition and persistence, five loblolly pines were treated with 0.5 percent WP lindane by the Accutrol system. An equal number of trees were similarly treated by conventional spraying. Samples of bark from each tree were collected at 0-day and at 2 months for quantitation of lindane by GLC analysis. Bark residues were determined, by the techniques previously described, on the day of application and 2, 4, 6, and 9 months after treatment.

A simple test was done to determine the amount of chlorpyrifos that rubs from treated bark surfaces onto clothing. Pieces of cotton cloth 12 cm^2 were rubbed over bark surfaces treated with each chlorpyrifos concentration according to the schedule in table 21. Samples were taken by firmly rubbing the cloth over the treated bark surface immediately after spraying (wet) and 2 hours after treatment (dry). The cloth was then folded several times with the contacted surface to the inside, tied, and stored in a freezer. All samples were placed in large culture tubes and extracted with 40 ml ethyl acetate for 48 hours. They were then dried with Na_2SO_4, and appropriate dilutions were made and analyzed as previously described.

RESULTS

Chlorpyrifos was much more persistent on pine bark than lindane, while chlorpyrifos-methyl was intermediate in persistence (table 22). The rate of dissipation of both chlorpyrifos and chlorpyrifos-methyl was independent of dosage at the concentrations tested.

There appeared to be no correlation between preventive efficacy of these materials (tables 12 and 13) and their persistence on bark (table 10). Considering the greater toxicity of both chlorpyrifos and chlorpyrifos-methyl than lindane in topical toxicity tests (Hastings and Jones 1976), it is surprising to find that lindane, while apparently less persistent than chlorpyrifos and chlorpyrifos-methyl, is superior to both materials in providing long-term protection against the SPB. The amount of lindane calculated from residue analysis to be present on bark 6 months after treatment with 0.5 percent lindane was 0.05 percent. This concentration of lindane was less effective immediately after applications than the 0.5 percent lindane 6 months after application. One possible explanation, consistent with the data, involves the alteration of lindane to a more toxic

product during exposure under field conditions. A second possible explanation is that a significant amount of lindane may have been bound and not extractable by leaching or maceration of bark. Experiments on dissipation of ^{14}C lindane from bark under appropriate conditions are in progress to test this possibility.

When bark residues of fenitrothion were below 3,500 p/m, beetles constructed galleries (tables 15 and 23). Lindane, however, continued to prevent gallery construction at very low residues.

In bioassays immediately after treatment, bark residues containing over 3,500 p/m of carbaryl failed to prevent attack (table 7).

Chlorpyrifos-methyl, emulsifiable concentrate (EC), was readily lost by sprinkling water over bark 10 minutes or 2 hours after application of insecticide (table 20). In comparison, lindane (EC) levels at 2 hours were essentially unaffected by washing; 17 percent was lost by sprinkling 10 minutes after application (WP). Loss of lindane (WP) was approximately twice that of lindane (EC) at the 10-minute wash time. Chlorpyrifos-methyl is obviously quite persistent in bark if rain does not occur for an extended time after treatment. However, these test results show that loss of chlorpyrifos-methyl from treated trees would be large if rain occurs shortly after application.

Adjuvants applied to increase persistence of chlorpyrifos and lindane were generally only slightly effective for intervals up to 9 months after treatment. Plyac® was the most effective of the six sticker materials tested (table 24). No efficacy tests were carried out with these adjuvant-insecticide mixtures.

Drift of lindane (0.5 percent WP) applied as a spray by two foam spray systems was only slightly less than with a conventional spray system.

Preliminary results of comparison of sprays prepared from EC and WP formulations of lindane indicated that the WP formulation was most compatible with all of the low-drift systems. The desired foam generated by these spray systems was at least partially destroyed by the EC formulation. Consequently, WP formulation was used in all subsequent experiments.

Quantitative comparisons of spray drift generated from three spray systems were made by GLC analyses of lindane residues at each of 48 sampling stations in the downwind spray pattern of each system (table 25). Comparative drift with each system was evaluated also by use of dyed spray on Kromekote cards at each sampling station. Results are in general agreement with those obtained by GLC analyses.

In three experiments with each spray system, results indicate that the drift range from the conventional spray system was not significantly different from the Accutrol or the Delevan foam systems. Both foam systems utilized Accutrol adjuvant. To the contrary, the degree of drift based on visual observations during spray applications appeared to be reduced by each foam system. Although results indicate general agreement between the Kromekote and GLC assay systems, the GLC method is considerably more sensitive (Barry and others 1978) and in completed analyses, spray drift was detected at certain distant stations by GLC and not by the Kromekote assay.

Deposition and persistence of lindane (0.5 percent WP) on pine bark with the Accutrol system was no greater than that obtained with the conventional system. In five replications with each system, 2,531 ± 414 p/m lindane was deposited on bark with the Accutrol system compared with 2,962 ± 355 p/m with the conventional system. At 2 months after treatment, results of GLC analyses indicated that about 60 percent of the lindane applied by each system had dissipated.

The cloth contamination tests were done in Louisiana and Georgia. Table 26 shows the results of these tests. As would be expected, the amount chlorpyrifos rubbed off the bark increased as the concentration applied to the bark increased. Also, the amount removed by rubbing was considerably higher when rubbing was done before the treated bark had dried. This study indicated that after chlorpyrifos dries, it constitutes no human health hazard by contact.

SOIL MICROBE STUDIES

A. S. Jones and F. L. Hastings

PROCEDURES

Microbial studies were conducted on (1) effects of chlorpyrifos and fenitrothion on soil microbial populations, (2) metabolism of fenitrothion by forest soil fungi, and (3) metabolism of chlorpyrifos by pure cultures of forest soil fungi.

Effects on soil microbial populations.—Flasks were prepared by mixing 20 g of air-dried soil with 0, 1, 10, 50, and 100 p/m active ingredient (a.i.) of technical insecticide and adding distilled water to bring the soils to approximately field capacity.

After the mixture incubated for 2 or 4 weeks at room temperature (approximately 25° C), 100 ml of sterile distilled water was added to each flask and the soil suspension stirred on a magnetic stirrer for 15 minutes. Using sterile distilled water, dilutions of 1:50,000 were made for fungi and 1:500,000 for bacteria and actinomycetes. For each replicate, five plates each of Martin's Rose-Bengal Agar and Thornton's Agar were prepared for the fungi and bacteria, respectively. Colonies were counted after incubation at room temperature for 7 days. In addition, a time-course study was done with one soil, sampled before and 1, 7, and 14 days after the treatment with the various concentrations of chlorpyrifos and fenitrothion. This study provided additional information on stimulation and/or depression of bacterial and fungal populations. Table 27 characterizes the soils used in this study.

Metabolism of chlorpyrifos by forest soil fungi.—For the metabolic studies, Erlenmeyer flasks containing 50 ml of Czapek-Dox Broth (Difco Lab., Detroit, Mich., pH 7.3) were autoclaved, and 2.5 mg of ^{14}C-labeled chlorpyrifos was added aseptically to each flask. Liquid scintillation counting (LSC) of 1 ml aliquots established the initial level of radioactivity (cpm) for each culture flask. Three replicate flasks were then inoculated with four fungi, *Trichoderma harzianum, Penicillium multicolor, P. vermiculatum*, and a *Mucor* sp. Uninoculated flasks served as controls. After the selected incubation time, the flasks were harvested by homogenization and filtration of the mycelium onto a weighed filter paper. The culture filtrate was then extracted with methylene chloride, and the radioactivity in the organic and aqueous phases was determined by LSC. Thin-layer chromatography (TLC) and radiochromatographic scanning were used to locate and identify the insecticide and its metabolites, using known standards as references. This experimental procedure was repeated for 7-, 14-, and 28-day incubation times.

Aerobic soil metabolism of fenitrothion and chlorpyrifos.—A soil sample was taken from a loblolly pine stand on the laboratory grounds at Research Triangle Park, and the percentage of moisture was determined. Fifty g dry weight of soil was placed in each of four Erlenmeyer flasks. One flask was autoclaved for 30 minutes, weighed, and the moisture content readjusted; after 24 hours, it was reautoclaved for 60 minutes to provide a sterile control soil. The insecticide solution was prepared by dissolving 12.5 mg of analytical-grade insecticide in 10 ml of the stock solution of ^{14}C-labeled insecticide, filtering the solution through a 0.2 μ Millipore filter, and washing with an additional 10 ml of 95 percent ethanol. Four-ml aliquots of the resultant sterile solution were aseptically pipetted into the three remaining flasks and mixed with the soil to give a concentration of about 10 p/m. Each flask was "stoppered" with a trapping tower (Marvel and others 1978) and incubated at about 25°C for 28 days. The Drierite® moisture-trapping layers were changed as needed, and the Ascarite® CO_2 trap was changed after 7 days incubation and analyzed for $^{14}CO_2$ as described by Marvel and others (1978).

After 28 days of incubation, the trapping towers were dismantled and analyzed for trapped organic volatiles and $^{14}CO_2$, and the soils were extracted with 200 ml of ethyl acetate. The ethyl acetate extracts were concentrated to 25-ml and 10-μl aliquots counted by LSC. The soil was sampled for bound residues by combusting duplicate 200-mg subsamples and counting the $^{14}CO_2$ released. Gas chromatography of the ethyl acetate extracts was performed on a Tracor 560 with a flame photometric detector.

RESULTS

Effect on soil microbial populations.—In general, we saw no adverse effect on either fungi or bacteria from concentrations of fenitrothion ranging from 1 to 100 p/m (table 28). The various soils differed in the number of microorganisms per gram and in type of effect seen, but only in soil 4 at 100 p/m was there a significant reduction in population counts. In all other instances, the effect was a stimulation of population counts, usually at 10 or 50 p/m. In soil 6, the number of fungi increased with increasing concentration from 1 to 50 p/m and was still elevated at 100 p/m.

Table 29 records the effect of chlorpyrifos on soil microbial populations. In soil 2, numbers of fungi decreased significantly with increasing concentrations of chlorpyrifos, while at 1 p/m a significant increase in bacterial colonies was seen. In soils 3, 4, and 5 the differences were not significantly related to the concentration of chlorpyrifos.

Table 30 shows populations of fungi isolated from a single soil treated with fenitrothion and chlorpyrifos and incubated for 1, 7, and 14 days. Data on effects of treatment and incubation time was subjected to analysis of variance F test and Duncan's multiple range test.

For chlorpyrifos, the analysis of variance indicated that incubation time was much more significant than treatment

(P = 0.003 and P = 0.1679, respectively). When Duncan's multiple range test was applied to data for each day, only the 50-p/m concentration of chlorpyrifos at day 7 was significantly different from the control. Examination of the data suggests that one replicate in that series had a very low colony count.

The analysis of variance for fenitrothion showed a small treatment effect as well as the strong incubation time effect (P = 0.0494 and P = 0.0003, respectively). Duncan's multiple range test applied to data from each day indicated that at day one, 100 p/m fenitrothion had significantly increased the colony count. Smaller increases seen at the lower concentrations were not significantly different from the controls. By day 14, the colony counts for 50 and 100 p/m were significantly lower than in the control. However, the mean colony count over the 14 days of incubation was not significantly different for any treatment (Duncan's multiple range test). This fact, coupled with the increases seen at day 1, and the lack of adverse effect in the previously described studies with five different soils, indicates that fenitrothion itself is not toxic to soil fungi at concentrations up to 100 p/m. The decline in numbers seen at 100 p/m in the time-course study at 7 and 14 days is more probably explained as a natural decline in populations caused by the exhaustion of available nutrients in the soil by the early, rapid growth of the population at this concentration.

Aerobic soil metabolism of fenitrothion and chlorpyrifos.—Studies using ^{14}C-labeled fenitrothion and chlorpyrifos in sterile and nonsterile soil were run to determine whether soil microorganisms can metabolize these insecticides and to identify degradation products. In a preliminary study using soil from the Research Triangle Park area, only the parent compound, fenitrothion, was recovered after 28 days incubation.

Another soil metabolism study using ^{14}C-labeled chlorpyrifos and fenitrothion was established and incubated for 56 days. At the end of the incubation period, the treatment and sterile control flasks were analyzed for trapped volatilized insecticides, ^{14}C-labeled CO_2 produced by metabolism of the insecticide molecules, organic solvent extractable residues of parent compound and metabolites, and unextractable bound residues. Total recovery of radioactivity from the samples was 85, 86, and 81 percent for the sterile control and the two treatment replicates, respectively. Of the applied radioactivity, 53, 55, and 55 percent, respectively, was extracted with organic solvent from the control and treatment replicates, while the soil-bound fractions contained 32, 31, and 26 percent. A trace of radioactivity was recovered as $^{14}CO_2$ in the treatments only, and no radioactivity was found in the traps for volatilized insecticides. TLC and LSC of the organic extracts indicated that about 46 to 47 percent of the applied radioactivity was present as parent compounds after 56 days of incubation in both control and treatment flasks. Approximately 12 percent of the radioactivity in the organic extract of the control flask was found in three breakdown products. Approximately 15 percent of the organic extracts from the treatment flasks was found as breakdown products. Although the half-life of the two insecticides in this experiment was approximately 56 days, breakdown appeared to be primarily the result of chemical action as opposed to microbial degradation, since the sterile control showed similar disappearance rates and products.

Metabolism of chlorpyrifos by forest soil fungi.—Table 31 presents the results of the time-course study on the metabolism of chlorpyrifos in pure cultures of four soil fungi grown in Czapek's medium. It is difficult to draw any conclusions from this experiment due to the rapid loss of the radioactive label from the system. A 30 percent loss of radioactivity from all flasks, including the sterile controls, occurred after only 7 days; by day 28, over 70 percent was lost. This loss was probably the result of very rapid volatilization of the parent compound, chlorpyrifos, from an aqueous medium (personal communication, Dow Chemical Co.). TLC of the organic and aqueous extracts of the cultures after the various incubation intervals revealed only chlorpyrifos in the organic layer and only 3, 5, 6-trichloro-2-pyridinol in the aqueous layer. Although there appeared to be more of the water-soluble product in the *Penicillium* and *Mucor* cultures, definitive conclusions on the relative importance of chemical and microbial degradation of chlorpyrifos cannot be made until a method is found to reduce the volatility of chlorpyrifos in an aerobic aqueous system.

SOIL AND LITTER MESOFAUNA STUDIES

F. L. Hastings, A. S. Jones, and C. K. Franklin

PROCEDURES

In a field study, the effects of lindane (0.5 percent) and chlorpyrifos-methyl (0.5 and 1 percent) on mesofauna in forest litter were evaluated. Plots for litter and soil sampling were established in each of the treatment and control sites on lines between trees selected for the field test. Fifteen samples each of forest floor (litter) and soil from each treatment plot were collected a week prior to the insecticide spray to establish pretreatment population levels of five categories of animals: (1) orbatid mites, (2) mesostigmatid mites, (3) trombidiform mites, (4) collembolans, and (5) other arthropods (e.g., ants, beetle larvae, aphids).

From the same sites, samples were taken 1, 6, 23, and 75 weeks after treatment to monitor any population decreases and to track subsequent fauna recovery.

Samples were collected with a brass ring 3 cm deep and 20 cm^2 in area. The ring was placed on the forest floor and a cut made around the outside edge down to the mineral soil. The floor from within the ring was removed and placed in a plastic bag. Next, a small block of hardwood was placed on the ring and tapped with a hammer until the top of the ring was at the top of the mineral soil. The ring and enclosed soil were lifted with a squared-off trowel, and the approximately 60-cm^3 sample was placed in a plastic bag. Samples were placed on modified Tullgren funnels for 7 days and then ovendried. The percentage of soil moisture was calculated on an ovendry basis. Invertebrates driven from the samples were caught in alcohol vials and classified by microscopic examination.

The persistence of insecticide residues associated with mesofaunal populations was also determined by GLC. Soil and litter samples were homogenized in a Waring® blender, and 25- and 50-g subsamples (respectively) were extracted two times with solvent (acetone for chlorpyrifos-methyl and hexane for lindane). The extracts were concentrated to 1 ml and analyzed with a Hewlett-Packard® model 7620 gas chromatograph. Conditions for analysis were:

Flame-ionization detector oven-programed from 180° to 290° C at 20°/min after an initial isothermal run of 10 min for lindane and 15 min for chlorpyrifos-methyl; 6-ft by 1/8-in stainless steel column packed with 2 percent OV-17; injector temperature 200° C; detector temperature 300° C.

Peaked areas were quantified by comparison to standard curves, and retention times were verified with standards run during the analysis and with spiked samples.

RESULTS

Tables 32 and 33 indicate changes in numbers of soil and litter invertebrates during 75 weeks after application of lindane (0.5 percent) and chlorpyrifos-methyl (0.5 percent and 1 percent). Data are expressed as number of organisms per sample volume. Values are corrected for pretreatment levels and moisture content in computing statistical significance.

Litter organisms were most prevalent and most affected by insecticidal treatments. The most sensitive organisms appeared to be the collembolans, which were significantly depressed (P = 0.01) by both lindane and chlorpyrifos-methyl 6 and 23 weeks after treatment. Numbers of mites and other organisms were reduced for 23 weeks after treatment; thereafter, they returned to pretreatment levels. Interestingly, these organisms appeared to be affected to the same extent by lindane and chlorpyrifos-methyl. This phenomenon was unexpected because organophosphates are generally not as persistent as organochlorines. However, as table 34 indicates, the 0.5 percent chlorpyrifos-methyl was persistent for at least 5 months in forest litter.

Soil invertebrates were not very numerous and, with few exceptions, were not severely affected by these insecticides. Collembolans appeared sensitive, as in the litter, but recovered by the final sampling period. Mesostigmatid populations were depressed at 6 weeks but were somewhat stimulated at 23 weeks. The residue data indicate that only small amounts of insecticide actually passed through the litter or F layer. This fact, along with the metabolic potential of soil microorganisms in the F layer, probably explains the lessened impact of these insecticides on soil animals.

SELECTIVE APPLICATION OF TOXICANTS

C. W. Berisford and U. E. Brady

PROCEDURES

A study was designed to determine if SPB attacks could be prevented by selectively applying toxicants to: the bottom two meters, the lower half, and top half of tree boles. These treatments were compared to entire bole treatments which had previously been shown to be effective.

Five treatment blocks were established in three infestations (Clarke, Morgan, and Oglethorpe Counties, Ga.) during September-November, 1979. Blocks 1, 3, and 4 (Clarke County) were located in a 40-year-old stand of mixed shortleaf and loblolly pines, predominantly the former (established September 27 and October 17 and 18, respectively). Block 2 (Oglethorpe County) was located in a 25-year-old slash pine (*P. elliottii* Engelm.) plantation (established October 12). Block 5 (Morgan County) was located in a 30-year-old mixed loblolly pine-hardwood forest (established November 7). Trees ranged from 20.5 to 29 cm d.b.h. and 15 to 24 m total height (means 24.6 and 21.2, respectively). SPB populations in these stands were high.

Each block consisted of three treatments–sprayed basal 2 m only, sprayed basal 6.6 m only (considered to midbole of noncrown portion), and sprayed full length, with an additional set of unsprayed trees as controls. Four trees received each treatment within each block; 16 trees per block and a total of 72 trees were treated. Block 4 included only the basal 6.6-m and full-length treatments. Treated parts of trees were sprayed to runoff at 200 to 300 lb/in^2 pressure with a water emulsion of one of two compounds–0.5 percent lindane (used in blocks 1 through 4), or 2 percent chlorpyrifos (used in block 5). Bark samples were taken about 1 day after spraying for residue analysis to verify spray coverage and concentration.

Alternate trees in each treatment were baited at midbole with 1 ml of frontalure released from dispensers described by Gammill and others (1978). Baits were replaced on days 15 and 30 as needed.

A 20- by 50-cm screen trap coated with Stickem Special® was placed at midbole of each tree to monitor beetle visits. Traps and trees were inspected at 15-day intervals following treatment, and evidences of beetle attack and estimates of SPB trapped on screens were recorded. On day 45, screens and baits were removed from all trees and absolute counts were made of SPB trapped.

On day 60, one tree from each treatment and block was felled and bark samples taken at 2-m intervals along the bole beginning at 1 m. Presence or absence of any SPB life stage (parent adult, egg, larval instar, pupa, brood adult) and the success or failure of attacks were noted. Attacks were recorded as successful if eggs were present in parent galleries.

When SPB activity began in the spring of 1980, a second series of tests was initiated. Twelve treated trees were sprayed on April 2 in a slash pine plantation. All treated trees were sprayed with lindane above 5 m (midbole) up to 11 m on the bole. Four untreated trees were marked as checks. Two checks and two treated trees were baited with frontalure. An additional six trees were treated on May 2 from 4 to 10 m above the ground. Three of these trees were baited. Residue samples were taken from all test trees.

A final set of tests was installed on July 14. Six trees each were treated with 0.5 percent lindane on the basal 6 m (lower half), from 5 to 11 m (midbole), or the entire bole. Six untreated checks were designated. Alternate trees were baited with frontalure at midbole. No trees were treated on the basal 1 to 2 m because all previous tests showed this treatment to be ineffective.

RESULTS

Table 35 presents the results of the preventive control tests. During 1979 only trees with 100 percent bole coverage were protected, but two of these trees were attacked and one was killed. Subsequent residue analysis indicated that this tree was not sprayed. Treated portions of trees sprayed on the basal 2 and 6.6 m were adequately protected (no attacks or gallery construction), but attacks above the sprayed areas resulted in tree mortality. All baited trees receiving less than whole-bole treatments died. About 20 percent of the unbaited trees survived, apparently because few beetles attacked them.

The results of these preliminary tests showed that spray coverage higher than midbole was needed for adequate protection.

On the test set up on April 2, 1980, all checks were attacked and killed by April 28. All treated trees (full height and upper half) were protected with one exception. This tree had two SPB pitch tubes below the treated area on April 28. It was subsequently mass-attacked and killed.

The trees in this series of tests were in areas with high SPB populations. Twenty-seven other unbaited and untreated trees were killed in this spot during May and June.

The final tests of applications above and below midbole produced similar results. All untreated checks and trees treated below midbole were killed and none of those treated above midbole or over the entire bole was killed. One above midbole treatment had an unsuccessful attack (table 35).

Analyses of residues showed deposition of lindane and Dursban® on the sprayed portions of trees to be similar to those in previous studies (Berisford and others 1980; Brady and others 1980; Mizell and others 1981).

Treatment of the basal 2 m, or the lower half, of pine boles provided little or no protection from SPB attack. Treatment of the entire bole into the lower portion (about

20 percent) of the crown provides excellent control, as had been demonstrated in previous tests.

The preliminary data indicate that treatment of the midbole area where SPB attacks are usually initiated (Coulson and others 1976) gives good protection. Effective and ineffective treatments are shown in figure 9. If it proves feasible, utilization of this type of treatment on an operational basis will provide two benefits: (1) It will require less insecticide for protection (about 30 percent less), thereby reducing costs. (2) Because excessive runoff is reduced by not treating the lower bole, contamination of the immediate area and the impact of the toxicants on nontarget organisms will be substantially reduced.

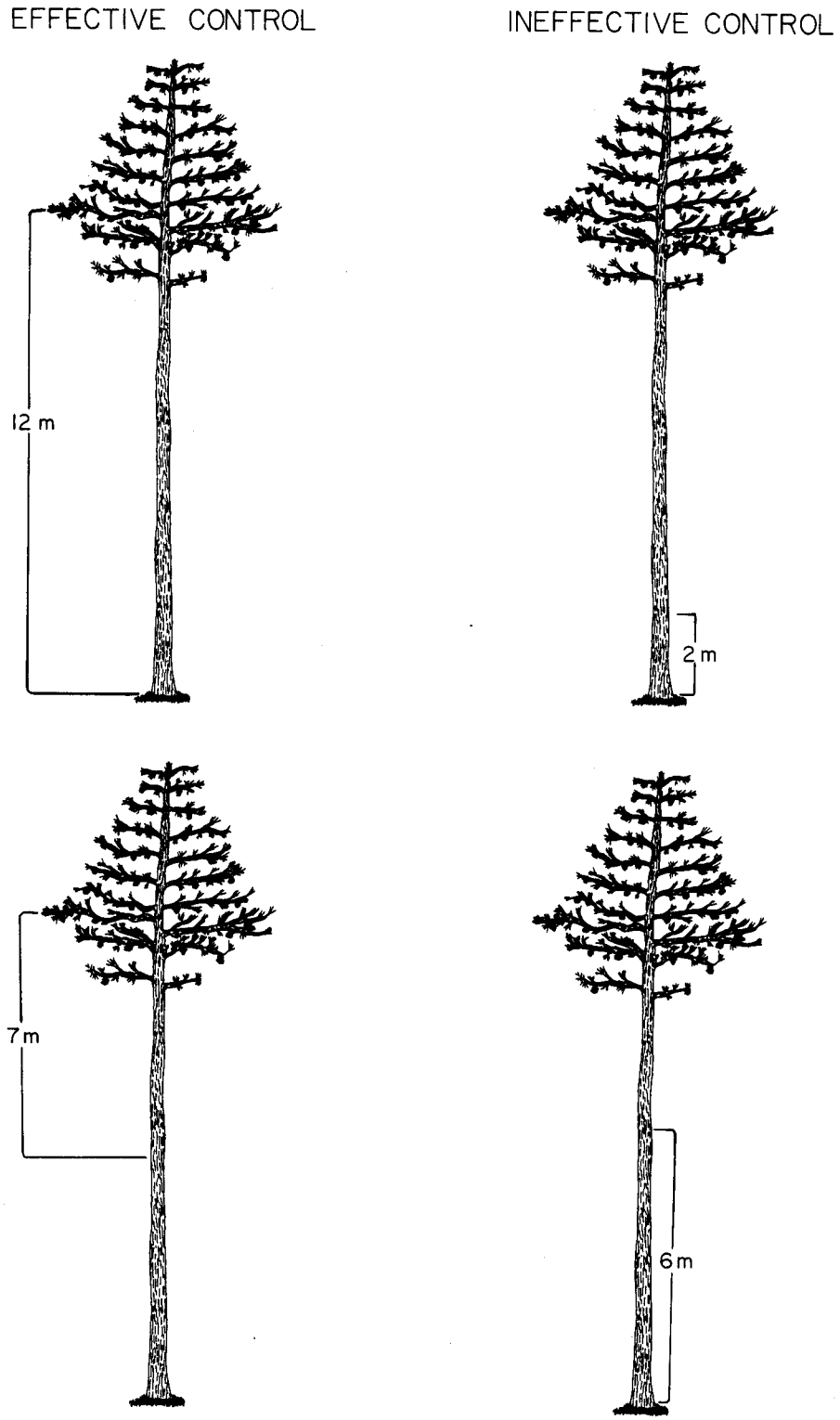


Figure 9.–Sections of bole sprayed with insecticide to prevent SPB damage.

OBSERVATIONS ON PHYTOTOXICITY

F. L. Hastings, A. S. Jones, and C. K. Franklin

High levels (2, 4, and 8 percent) of chlorpyrifos, chlorpyrifos-methyl, and fenitrothion were applied by hydraulic sprayer to the point of runoff on loblolly and shortleaf pines. Neither pine species showed any phytotoxic effect.

The following woody plants were found in the chlorpyrifos and chlorpyrifos-methyl plots in North Carolina: willow oak, *Quercus phellos* L.; post oak, *Q. stellata* Wangenh.; northern red oak, *Q. rubra* L.; sweetgum, *Liquidambar styraciflua* L.; red maple, *Acer rubrum* L.; flowering dogwood, *Cornus florida* L.; winged elm, *Ulmus alata* Michx.; eastern red cedar, *Juniperus virginiana* L.; common chokecherry, *Prunus virginiana* L.; blackhaw, *Viburnum prunifolium* L.; sourwood, *Oxydendrum arboreum* (L.) DC.; blueberry, *Vaccinium* sp.; pignut hickory, *Carya glabra* (Mill.) Sweet; eastern persimmon, *Diospyros virginiana* L.; sassafras, *Sassafras albidum* (Nutt.) Nees; hawthorn, *Crataegus* sp. The fenitrothion plot contained a number of these same woody plants with the exception of post oak, northern red oak, winged elm, chokecherry, sassafras, and blueberry. Additional plants in this plot were white oak, *Q. alba* L.; blackjack oak, *Q. marilandica*; water oak, *Q. nigra* L.; American elm, *Ulmus americana* L.; and black tupelo, *Nyssa sylvatica* Marsh. var. *sylvatica*.

Neither chlorpyrifos nor chlorpyrifos-methyl killed understory plants at either concentration. The only phytotoxic symptoms were leaf kill and dieback in twigs of blueberry. These symptoms were still evident after 1 year.

The 4 percent fenitrothion caused leaf damage to black tupelo, red maple, blackjack oak, and hawthorn. Damage to the red maple was most severe, but no mortality occurred within 12 months after spraying. The 8 percent concentration caused leaf damage to the red maple, blackjack oak, flowering dogwood, sweetgum, and pignut hickory.

SUMMARY

Chlorpyrifos (Dursban 4E) was registered with the EPA in February 1979 for remedial and preventive treatment of pines to reduce damage and possible mortality caused by infestations of SPB. The insecticide is to be applied as a 1 percent aqueous spray to individual trees using suitable hand- or power-operated ground spray equipment. The hanging-bolt bioassay indicated that this concentration protected trees in Georgia from SPB attack and egg gallery formation for 4 months. In Louisiana, protection against attack was for 3 months, and protection from egg gallery formation was for 7 months. In Mississippi, protection from egg gallery formation lasted for approximately 5 months.

In studies of prevention of tree mortality, 1 percent chlorpyrifos was equivalent to lindane in 10 study sites in Mississippi, which were kept under continual attack for up to 1 year. The results were similar in Georgia, although beetle populations were lower.

Remedial studies in which emergence cages or cans were placed in the laboratory indicated 1 percent chlorpyrifos to be equal to lindane, or slightly superior. In studies where emergence was observed outdoors, 1 percent chlorpyrifos was significantly more effective than lindane (94 percent mortality vs. 61 percent).

Phytotoxicity and human-exposure safety data supported this registration. Chlorpyrifos concentrations of 2, 4, and 8 percent were shown to cause no problems in southern pines. There was some burning of understory vegetation; however, no mortality resulted and 12 months after application there was no sign of damage. By wiping a cloth over treated bark, it was shown that after chlorpyrifos dries, it constitutes no human health hazard by contact. This is particularly important for home use.

Other safety data indicated that chlorpyrifos is unlikely to be harmful to soil microbes. However, with one soil which had a high nitrogen content, some reduction in fungal propagules was observed. In this same soil, 1 p/m chlorpyrifos stimulated bacterial growth.

In Georgia, hanging-bolt studies indicated that 2 percent fenitrothion protected trees from attack and egg gallery formation for at least 3 months. The hanging-bolt and standing-tree techniques were compared in Mississippi. Two percent fenitrothion appeared to be effective against SPB for more than 6 months. Efficacy differences might be attributed to differences in beetle populations or weathering effects. Residue studies indicated that fenitrothion persisted longer in Mississippi than in Georgia. Because of the rapid movement of SPB infestations, an insecticide with the safety characteristics of fenitrothion, which is effective for 3 months, is believed to be an appropriate substitute for lindane.

Remedial studies in Georgia, Mississippi, and North Carolina indicated that 1 percent fenitrothion was superior to lindane in reducing survival of beetles emerging from infested trees.

Fenitrothion caused no phytotoxic effects in southern pines sprayed with 4 percent and 8 percent concentrations. There was some leaf damage to understory vegetation, but no mortality was observed after 12 months in red maple, the most severely damaged species.

In general, fenitrothion caused no adverse effects to either fungi or bacteria at concentrations in soil ranging from 1 to 100 p/m. It did reduce fungal propagules somewhat in one soil at 100 p/m, but in many cases population counts were higher.

A highly reproducible, simple, and economical technique (hanging-bolt) was developed for assessing preventive efficacy of insecticides against the SPB. This technique does not require standing trees and thus eliminates the problems

of spot dieout during a test and of obtaining long-term commitments from landowners. This procedure may be useful for testing insecticides against a variety of primary bark beetles.

The laboratory acute toxicity screening indicated that 17 of the 29 materials evaluated were more toxic than lindane against the SPB. Field bioassays showed that nine of these insecticides could replace lindane as a remedial control.

Six adjuvants were tested for increasing persistence of lindane and chlorpyrifos for a period of 9 months. These materials were only slightly effective. Plyac was the most effective of the six sticker materials tested with lindane, while NuFilm® 17 was most effective with chlorpyrifos. No difference in deposition or persistence of lindane was found when the antidrift foam, Accutrol, was compared to conventional hydraulic application.

Chlorpyrifos-methyl (Reldan® 4E) was evaluated in the same manner as chlorpyrifos and fenitrothion in Mississippi and Georgia. These studies indicated that this insecticide was as effective as chlorpyrifos in preventive and remedial SPB control procedures. Lower concentrations of chlorpyrifos-methyl were tested in North Carolina, and results indicated that even 0.5 percent was as effective as lindane for 2 months as a preventive. Because of its efficacy, low mammalian toxicity, and transient effects on litter mesofaunal populations, chlorpyrifos-methyl appeared to be an excellent replacement for lindane. Unfortunately, the producer decided against the field use of this material.

Selective application of toxicants to different parts of pine tree boles indicated that treatment of the basal 2 m or even the lower half of pine boles provides no protection from SPB attack. However, treatment of the upper portion of the bole is as effective as treatment of the entire bole. Data indicate that upper-bole treatment provides adequate protection with about a 30 percent reduction in insecticide. Such treatment can be done at less cost and it has less impact on nontarget areas.

LITERATURE CITED

Barry, J. W., R. B. Ekblad, G. P. Markin, and G. C. Trostle.
1978. Methods for sampling and assaying deposits of insecticidal sprays released over forests. USDA Tech. Bull. 1596, 162 p. U.S. Gov. Print. Off., Washington, D.C.

Bennett, W. H., and L. S. Pickard.
1966. Benzene hexachloride emulsion as a summer control of the southern pine beetle. J. Econ. Entomol. 59:484.

Berisford, C. W., and U. E. Brady.
1976. Duration of protection of loblolly pines from *Ips* beetles by lindane. J. Econ. Entomol. 69:357-358.

Berisford, C. W., U. E. Brady, R. F. Mizell, J. H. Lashomb, G. E. Fitzpatrick, I. R. Ragenovich, and F. L. Hastings.
1980. A technique for field testing insecticides for long-term prevention of bark beetle attack. J. Econ. Entomol. 73: 694-697.

Berisford, C. W., H. M. Kulman, R. L. Pienkowski, and H. J. Heikkenen.
1976. Factors affecting distribution and abundance of hymenopterous parasites of *Ips* spp. bark beetles in Virginia (Coleoptera: Scolytidae). Can. Entomol. 103:235-239.

Brady, U. E., C. W. Berisford, T. L. Hall, and J. S. Hamilton.
1980. Efficacy and persistence of chlorpyrifos, chlorpyrifos-methyl and lindane for preventive and remedial control of the southern pine beetle. J. Econ. Entomol. 73:639-641.

Coulson, R. N., A. M. Mayyasi, J. L. Foltz, F. P. Hain, and W. C. Martin.
1976. Resource utilization by the southern pine beetle, *Dendroctonus frontalis* Zimm. (Coleoptera: Scolytidae). Can. Entomol. 108:353-362.

Daum, R. I.
1970. Revision of two computer programs for probit analysis. Bull. Entomol. Soc. Am. 16:10-15.

Gammill, W. J., G. E. Fitzpatrick, and W. W. Neel.
1978. A dispenser for release of the aggregating pheromone of the southern pine beetle. J. Ga. Entomol. Soc. 13:95-97.

Hastings, F. L., and A. S. Jones.
1976. Contact toxicity of 29 insecticides to southern pine beetle adults. USDA For. Serv., Res. Note SE-245, 4 p. Southeast. For. Exp. Stn., Asheville, N. C.

Jump, B. J., and C. H. Tsao.
1973. Control of southern pine beetles by spraying standing and felled trees with BHC. J. Ga. Entomol. Soc. 8:203-209.

Kenaga, E. E., and C. S. End.
1974. Commercial and experimental organic insecticides. Entomol. Soc. Am. Spec. Publ. 74-1, 77 p.

Marvel, John T., B. B. Brightwell, J. M. Malik, M. L. Sutherland, and M. L. Rueppel.
1978. A simple apparatus and quantitative method for determining the persistence of pesticides in soil. J. Agric. Food Chem. 26:1116-1120.

Mizell, R. F., W. W. Neel, and J. H. Lashomb.
1981. Field evaluation of fenitrothion for prevention of tree mortality from SPB attack. J. Econ. Entomol. 74:30-32.

Smith, R. H.
1970. Length of effectiveness of lindane against attacks by *Dendroctonus brevicomis* and *D. ponderosae* in California. J. Econ. Entomol. 63:1180-1181.

Sokal, R., and F. Rohlf.
1969. Biometry. 776 p. W. H. Freeman Co., San Francisco.

Appendix

Table 1.–Toxicity of insecticides applied to southern pine beetles[a]

Insecticide	Insects treated	Slope ± S.E.	LD_{50}[b]	95% fiducial limits	LD_{90}[b]	95% fiducial limits	Relative potency[c]	95% fiducial limits
Permethrin	600	2.12 ± 0.22	2.16	1.73–2.56	8.68	7.07–11.47	13.63	–
Chlorpyrifos-methyl	479	2.28 ± 0.71	3.38	2.76–4.12	9.83	6.53–15.0	9.75	7.27–13.09
Stirofos	700	2.73 ± 0.74	4.05	3.41–4.81	11.80	7.41–19.1	8.12	6.12–10.78
Chlorpyrifos	481	3.13 ± 0.40	5.63	4.55–6.97	16.38	9.57–28.5	5.85	4.29–7.97
Naled	880	3.08 ± 0.29	7.45	6.23–8.87	21.69	16.2–29.4	4.42	3.37–5.80
Fenithrothion	995	2.48 ± 0.37	8.66	7.46–10.0	25.20	19.6–32.9	3.80	2.91–4.97
Etrimphos	540	3.27 ± 0.29	8.77	7.26–10.6	25.51	17.9–36.8	3.76	2.81–5.03
Pirimiphos-methyl	600	2.48 ± 0.24	8.97	7.20–11.1	26.11	19.1–36.1	3.67	2.72–4.97
Dicrotophos	840	2.93 ± 0.36	8.99	7.68–10.5	26.15	19.8–35.1	3.66	2.79–4.82
Pirimiphos-ethyl	580	2.87 ± 0.29	10.42	8.11–13.3	30.32	22.3–41.7	3.16	2.33–4.32
Phosmet	600	2.37 ± 0.30	12.51	10.4–15.0	36.42	24.6–54.8	2.63	1.98–3.50
Carbophenothion	440	2.66 ± 0.68	19.37	14.9–25.1	56.38	39.0–82.5	1.70	1.24–2.35
Carbofuran[d]	720	1.77 ± 0.35	22.62	11.1–39.1	119.6	59.0–1,786	1.47	–
Methomyl[d]	559	1.18 ± 0.15	24.72	18.6–31.6	299.1	184–638	1.35	–
Aminocarb[d]	680	1.36 ± 0.24	25.02	16.2–35.1	218.9	118–835	1.33	–
Diazinon	350	2.91 ± 0.36	28.29	21.5–37.1	82.32	54.8–125	1.16	.83–1.63
Ronnel	480	2.82 ± 0.32	32.70	26.7–40.2	95.18	58.9–156	1.01	.74–1.36
Lindane	360	3.62 ± 0.48	32.92	26.2–41.3	95.83	55.0–170	1.00	–
Dimethoate	480	3.20 ± 0.33	37.46	31.2–45.1	109.0	68.9–175	.88	.66–1.17
Methamidiphos[d]	560	1.94 ± 0.24	42.70	34.9–50.4	195.0	148–299	.78	–
Fonofos	580	2.06 ± 0.55	44.53	36.6–54.2	129.6	83.0–206	.74	.55–1.00
Carbaryl[d]	478	1.80 ± 0.20	129.2	108–155	663.7	470–1,116	.26	–
Acephate[d]	600	1.90 ± 0.20	217.0	186–252	1,023	762–1,587	.15	–
Propoxur	240		>253.8					
Chlordimeform	120		>126.9					
Methoxychlor	120		>126.9					
Cruformate	120		>126.9					
Propyl thiopyro-phosphate	120		>126.9					
Trichlorfon	120		>126.9					

[a]Values calculated from pooled data on parallel lines.
[b]μg/g body weight.
[c]Relative potency at LD_{50} and LD_{90} = LD lindane/LD candidate.
[d]Values calculated by individual probit analysis, and relative potency at LD_{50} only. Lines not parallel.

Table 2.–Analysis of variance of treatment effects

Response variable	df	Sum of squares	Mean square	F	Pr > F
PerDed-48[a]	41	10.3735	0.0405	6.25	0.0001
PertDead[b]	41	8.9735	.0119	18.34	.0001
PerDeBo[c]	41	7.2366	.1888	.93	.5874

[a]Percent mortality in beetles held for an additional 48 hours.
[b]Percent mortality of emerged beetles, corrected for 48-hour mortality.
[c]Percent mortality of beetles in the bolts.

Table 3.–Percent SPB mortality 48 hours after treatment with various insecticides

Insecticide	Concentration	Mortality[a] (mean)
		Percent
Chlorpyrifos-methyl	2.0	100 a
Chlorpyrifos	2.0	92 ab
Chlorpyrifos-methyl	1.0	83 abc
Pirimiphos-ethyl	2.0	79 abcd
Chlorpyrifos	1.0	78 abcd
Carbophenothion	2.0	75 abcde
Fenitrothion	2.0	69 abcde
Pirimiphos-methyl	2.0	68 abcde
Fenitrothion	1.0	68 abcde
Permethrin	1.0	63 bcde
Phosmet (encap)	2.0	63 bcdef
Etrimphos	1.0	63 bcdef
Permethrin	.125	61 bcdef
Permethrin	.5	56 cdefg
Pirimiphos-methyl	1.0	56 cdefg
Permethrin	.25	55 cdefg
Pirimiphos-ethyl	1.0	55 cdefg
Chlorpyrifos	.50	52 defg
Chlorpyrifos-methyl	.50	51 defg
Etrimphos	2.0	50 defg
Chlorpyrifos-methyl	.25	49 defg
Lindane	.50	45 defg
Fenitrothion	.50	45 defgh
Etrimphos	.50	44 defgh
Carbophenothion	1.0	44 defgh
Pirimiphos-ethyl	.50	44 defgh
Chlorpyrifos	.25	43 defgh
Phosmet (encap)	.50	42 defgh
Phosmet (EC)	.50	35 efghi
Phosmet (EC)	2.0	32 defhi
Phosmet (encap)	1.0	27 fghi
Fenitrothion	.25	27 ghi
Pirimiphos-ethyl	.25	25 ghi
Pirimiphos-methyl	.25	23 ghi
Phosmet (EC)	1.0	22 ghi
Pirimiphos-methyl	.50	20 ghi
Carbophenothion	.50	20 ghi
Etrimphos	.25	14 hi
Phosmet (encap)	.25	14 hi
Phosmet (EC)	.25	12 hi
Control	0	7 i
Carbophenothion	.25	4 i

[a]Percentages of mortality followed by a common letter do not differ significantly at the 0.05 level according to Duncan's multiple range test.

Table 4.—Total percent mortality of SPB after treatment with various insecticides

Insecticide	Concentration	Mortality[a] (mean)
	..... *Percent*	
Chlorpyrifos-methyl	2.0	97 a
Fenitrothion	2.0	95 a
Chlorpyrifos	2.0	94 ab
Chlorpyrifos	1.0	94 ab
Fenitrothion	1.0	92 abc
Etrimphos	2.0	91 abc
Chlorpyrifos-methyl	1.0	88 abcd
Pirimiphos-ethyl	2.0	86 abcde
Etrimphos	1.0	84 abcde
Chlorpyrifos	.5	83 abcdef
Phosmet (encap)	2.0	81 abcdefg
Pirimiphos-ethyl	1.0	79 abcdefgh
Pirimiphos-methyl	2.0	76 bcdefghi
Fenitrothion	.5	76 cdefghi
Etrimphos	.5	74 defghi
Carbophenothion	2.0	74 defghi
Pirimiphos-methyl	1.0	73 defghij
Chlorpyrifos-methyl	.5	73 defghij
Permethrin	1.0	73 defghij
Phosmet (encap)	1.0	72 defghij
Phosmet (EC)	2.0	70 defghij
Chlorpyrifos-methyl	.25	67 efghijk
Chlorpyrifos	.25	67 fghijk
Fenitrothion	.25	66 fghijkl
Phosmet (EC)	1.0	66 fghijkl
Pirimiphos-ethyl	.5	64 fghijkl
Phosmet (encap)	.5	61 ghijkl
Permethrin	.25	61 hijkl
Lindane	.5	61 hijkl
Etrimphos	.25	61 hijkl
Carbophenothion	1.0	60 hijklm
Permethrin	.125	59 ijklm
Permethrin	.5	58 ijklm
Phosmet (EC)	.5	58 ijklm
Pirimiphos-methyl	.25	51 jklmn
Pirimiphos-ethyl	.25	48 klmno
Pirimiphos-methyl	.5	48 lmno
Phosmet (EC)	.25	39 mno
Phosmet (encap)	.25	39 mno
Carbophenothion	.5	31 nop
Carbophenothion	.25	24 op
Control	0	21 p

[a]Percentages followed by a common letter do not differ significantly at the 0.05 level according to Duncan's multiple range test.

Table 5.—Mean length of egg galleries in laboratory forced-attack bioassay

Treatment	Months after treatment					
	1	2	3	4	5	6
	cm					
Control	20.75	57	97	88	34	215
0.5% lindane	0	0	3.5	7.5	14.5	0
0.5% chlorpyrifos-methyl	0	0	0	5	0	44
1.0% chlorpyrifos-methyl	0	70	0	12.5	14	54

Numbers are averages of four replicates.

Table 6.—Preventive control of successful SPB attack in field bioassays of three insecticides, Georgia

Treatment	Months after treatment			
	0	2	4	6
	Percent			
Lindane	98 ± 1[a]	91 ± 6	100	90 ± 10
1% fenitrothion	91 ± 7	30 ± 36	68 ± 16	61 ± 30
2% fenitrothion	96 ± 3	84 ± 13	96 ± 3	97 ± 5
2% carbaryl (UCSF-2)	50 ± 34	–	–	–
2% carbaryl (UCSF-2)[a]	90 ± 10	75 ± 26	–	–
2% carbaryl (Sevimol 4®)[a]	61 ± 27	69 ± 6	–	–
Control[b]	47 ± 10	43 ± 10	123 ± 29	8 ± 4

[a]Replicates applied 2 months after initial carbaryl application.
[b]Numbers for controls are actual numbers of attacks.
Values shown are: 100 – (treated/control × 100).

Table 7.—Preventive control of SPB gallery production in field bioassays of three insecticides, Georgia

Treatment	Months after treatment				
	0	2	4	6	10
	Percent				
Lindane	100	100	100	100	99 ± 1
1% fenitrothion	93 ± 8	27 ± 51	50 ± 40	62 ± 46	24 ± 21
2% fenitrothion	0	0	82 ± 9	91 ± 16	81 ± 3
2% carbaryl (UCSF-2)	62 ± 23	–	–	–	–
2% carbaryl (UCSF-2)[a]	83 ± 16	50 ± 56	–	–	–
2% carbaryl (Sevimol 4®)[a]	30 ± 7	48 ± 36	–	65 ± 35	–
Control[b]	280 ± 101	246 ± 108	262 ± 49	27 ± 27	487

[a]Replicates applied 2 months after initial carbaryl application.
[b]Numbers for controls are actual lengths of egg galleries in centimeters.
Values shown are: 100 – (treated/control × 100).

Table 8.—Pesticide residues on bark at indicated times after application, Georgia

Treatment	0-day	2 months	4 months	6 months	8 months	10 months
			p/m			
Lindane	2,521	382 (15)	107 (4)	71 (3)	79 (3)	58 (2)
1% fenitrothion	3,474	1,360 (39)	984 (28)	870 (25)	738 (21)	758 (22)
2% fenitrothion	7,050	3,305 (47)	1,588 (23)	1,802 (26)	1,280 (18)	1,475 (21)
2% carbaryl (UCSF-2)	3,608	–	–	794 (22)	<5	–
2% carbaryl (UCSF-2)[a]	4,169	2,022 (48)	–	–	–	–
2% carbaryl (Sevimol®)[a]	3,227	1,525 (47)	1,292 (40)	<5	–	–

[a]Replicates applied 2 months after initial carbaryl application.

Numbers in parentheses indicate percent of 0-day concentration.

Table 9.—Numbers of SPB trapped during 2-week periods on baited and sprayed trees at three sites, Camden County, Georgia

Site and weeks after treatment	Average number per tree					Control
	Lindane	Chlorpyrifos		Chlorpyrifos-methyl		
	0.5%	1%	2%	1%	2%	
Site 1:						
2	12.7	2.7	–	3.3	0.3	0
4	53.0	6.0	1.8	9.5	3.0	1.8
6	52.0	4.3	3.8	11.5	2.8	1.5
8	43.5	6.3	3.3	10.3	1.0	.3
10	12.8	4.0	4.5	19.8	1.0	.3
12	–	–	–	–	–	–
14	77.0	12.0	7.3	18.3	0	.8
16	36.0	3.3	.8	6.8	.8	.3
18	10.8	3.5	1.0	2.3	0	.5
20	18.0	1.3	.5	3.8	0	.5
22	6.0	2.0	3.0	6.0	.5	.2
24	10.0	3.0	.2	4.0	1.0	1.0
26	5.0	7.0	1.0	3.0	0	1.0
28	6.0	1.0	.2	2.0	.2	.5
30	8.0	2.0	2.0	4.0	.2	0
32	10.0	3.0	.2	4.0	.5	0
34	.2	.5	.5	.5	0	.5
36	2.0	.2	0	.2	0	0
38	2.0	1.0	1.0	1.0	0	0
40	0	0	0	0	0	0
42	0	0	0	0	0	0
44	0	0	1.0	.2	0	0
46	0	0	.2	.2	0	0
48	0	0	1.0	0	0	0
50	.2	0	0	0	0	0
52	.5	0	.2	0	.5	0
Site 2						
2	97.0	101.3	13.8	79.0	150.8	33.5
4	143.3	80.0	12.5	74.3	171.8	43.0
6	31.8	30.0	14.5	48.3	80.0	23.5
8	16.3	32.0	10.8	39.0	85.5	25.3
10	30.0	29.0	28.5	56.0	94.5	15.5
12	–	–	–	–	–	–

continued

Table 9.–Numbers of SPB trapped during 2-week periods on baited and sprayed trees at three sites, Camden County, Georgia, continued

Site and weeks after treatment	Average number per tree					Control
	Lindane	Chlorpyrifos		Chlorpyrifos-methyl		
	0.5%	1%	2%	1%	2%	
14	15.5	35.5	46.8	73.5	114.0	6.3
16	9.0	28.8	44.8	63.0[a]	21.5	(b)
18	6.3	12.3	14.8	12.0[a]	9.0	(b)
20	8.0	37.8	54.3	53.3[a]	28.3	(b)
22	6.0	13.0	46.0	13.0	16.0	(b)
24	15.0	24.0	26.0	21.0	26.0	(b)
26	29.0	31.0	12.0	22.0	19.0	(b)
28	4.0	11.0	11.0	22.0	21.0	(b)
30	4.0	5.0	11.0	4.0	8.0	(b)
32	–	–	–	–	–	(b)
34	3.0	3.0	5.0	4.0	2.0	(b)
36	5.0	2.0	6.0	2.0	1.0	(b)
38	3.0	1.0	2.0	4.0	1.0	(b)
40	1.0	2.0	3.0	3.0	1.0	(b)
42	1.0	1.0	.2	1.0	.2	(b)
44	1.0	1.0	2.0	1.0	1.0	(b)
46	0	0	1.0	0	0	(b)
48	0	0	1.0	1.0	0	(b)
50	.2	.2	.2	0	.2	(b)
52	.2	1.0	2.0	1.0	1.0	(b)
Site 3:						
2	56.5	13.8	136.8	24.3	383.5	122.8
4	366.3	87.8	192.3	28.3	936.3	49.8
6	223.5	22.3	73.3	21.8	322.3	69.5
8	106.5	40.5	113.8	32.0	303.0	28.8
10	20.0	11.0	31.0	9.0	75.0	25.0
12	28.0	9.0	53.0	19.0	99.0	12.0
14	29.0	1.0	18.0	16.0	41.0	9.0
16	13.0	5.0	32.0	44.0	43.0	7.0
18	2.0	1.0	2.0	4.0	13.0	5.0
20	5.0	3.0	11.0	8.0	18.0	3.0
22	6.0	4.0	30.0	16.0	38.0	3.0[c]
24	6.0	1.0	18.0	28.0	17.0	5.0[c]
26	7.0	4.0	33.0	26.0	16.0	32.0[c]
28	3.0	2.0	11.0	10.0	8.0	6.0[c]
30	2.0	1.0	13.0	4.0	15.0	7.0[c]
32	7.0	5.0	11.0	5.0	15.0	3.0[c]
34	.5	1.0	18.0	5.0	2.0	(b)
36	1.0	.5	6.0	3.0	2.0	(b)
38	1.0	.5	2.0	.5	11.0	(b)
40	.2	1.0	1.0	1.0	.2	(b)
42	1.0	.5	1.0	1.0	0	(b)
44	–	–	–	–	–	(b)
46	–	–	–	–	–	(b)
48	0	.2	.2	0	0	(b)
50	–	–	–	–	–	(b)
52	0	0	0	0	0	(b)

[a]One tree dead.
[b]All trees dead.
[c]Three trees dead.

Table 10.—Average residues (dry weight) on bark at 4-month intervals, Camden County, Georgia

Site and treatment	0-day	4 months	8 months	12 months
		p/m		
Site 1:				
0.5% lindane	908	289 (32)	168 (18)	215 (24)
1% chlorpyrifos	2,598	1,400 (53)	1,413 (54)	648 (25)
1% chlorpyrifos-methyl	12,370	634 (27)	696 (29)	623 (26)
2% chlorpyrifos	5,027	2,122 (42)	1,170 (23)	1,467 (29)
2% chlorpyrifos-methyl	5,038	1,317 (26)	1,779 (35)	1,581 (31)
Site 2:				
0.5% lindane	1,715	328 (19)	277 (16)	214 (12)
1% chlorpyrifos	3,894	1,830 (47)	1,401 (36)	897 (23)
1% chlorpyrifos-methyl	2,605	999 (38)	701 (27)	605 (23)
2% chlorpyrifos	7,515	4,473 (59)	2,453 (33)	2,403 (32)
2% chlorpyrifos-methyl	7,996	2,557 (32)	2,723 (34)	2,010 (25)
Site 3:				
0.5% lindane	1,130	131 (12)	200 (18)	41 (4)
1% chlorpyrifos	3,448	2,077 (60)	972 (28)	687 (20)
1% chlorpyrifos-methyl	2,435	928 (38)	814 (33)	401 (16)
2% chlorpyrifos	7,674	5,645 (74)	2,307 (30)	1,731 (22)
2% chlorpyrifos-methyl	3,693	2,867 (78)	1,073 (29)	611 (16)

Numbers in parentheses indicate percent of 0-day concentration.

Table 11.—Mean days after treatment to crown-color change in six different treatments at 10 active SPB sites

Treatment	Number of trees	Days to color change[a]	Standard error
Control	40	81 a	7.6
0.5% lindane	14	167 b	14.2
1.0% chlorpyrifos-methyl	20	176 b	11.9
2.0% chlorpyrifos-methyl	19	162 b	11.6
1.0% chlorpyrifos	23	178 b	11.0
2.0% chlorpyrifos	17	182 b	12.9

[a]Includes only treatment trees whose crown color changed.

Means followed by the same letter are not significantly different. Means compared by Studentized range test (Sokal and Rohlf 1969).

Table 12.—Percent control of SPB attack by three insecticides in field bioassay

Treatment	Months after treatment							
	0	1	2	4	8	10	12	15
				Prevention of successful attack				
0.5% lindane	94[a] ± 12	88 ± 7	96 ± 8	88 ± 12	86 ± 12	68 ± 10	84 ± 10	99 ± 2
1% chlorpyrifos	88 ± 16	92 ± 8	91 ± 12	88 ± 7	66 ± 17	40 ± 8	53 ± 25	67 ± 7
2% chlorpyrifos	93 ± 16	88 ± 20	93 ± 9	88 ± 12	89 ± 14	88 ± 4	76 ± 23	91 ± 10
1% chlorpyrifos-methyl	100 ± 0	–	96 ± 4	90 ± 17	83 ± 15	–	57 ± 11	87 ± 38
2% chlorpyrifos-methyl	100 ± 0	–	100 ± 0	96 ± 4	90 ± 14	–	70 ± 39	85 ± 14
				Reduction in length of egg gallery				
0.5% lindane	98 ± 6	100 ± 0	99 ± 3	93 ± 9	99 ± 2	87 ± 4	94 ± 6	98 ± 3
1% chlorpyrifos	94 ± 7	98 ± 3	91 ± 13	85 ± 8	22 ± 93	38 ± 17	62 ± 23	37 ± 13
2% chlorpyrifos	94 ± 12	98 ± 4	96 ± 6	90 ± 11	88 ± 27	85 ± 8	77 ± 33	86 ± 12
1% chlorpyrifos-methyl	100 ± 0	–	96 ± 6	94 ± 11	100 ± 0	–	61 ± 30	51 ± 18
2% chlorpyrifos-methyl	100 ± 0	–	100 ± 0	97 ± 3	100 ± 0	–	74 ± 35	71 ± 22

[a]SD = ± 1.

Numbers represent the average of treatments made in 1975 and 1976 with four replications of one tree/replicate. Values shown are: 100 – (treated/control × 100).

Table 13.—Prevention of SPB attack and egg-gallery construction in forced-attack tests, Georgia

Treatment	Months after treatment						
	0	1	2	4	6	10	12
				Prevention of successful attack			
0.5% lindane	100 –	100 –	94 ± 10	90 –	67 –	67 ± 33	64 ± 12
1% chlorpyrifos	94 ± 10	94 ± 10	82 ± 20	80 –	60 –	50 ± 29	43 ± 20
2% chlorpyrifos	100 –	83 ± 18	94 ± 10	90 –	93 –	83 ± 29	64 ± 12
				Reduction in length of egg gallery			
0.5% lindane	100 –	100 –	100 –	100 –	65 –	79 ± 25	62 ± 25
1% chlorpyrifos	98 ± 3	98 ± 4	88 ± 2	81 –	61 –	74 ± 18	60 ± 13
2% chlorpyrifos	100 –	99 ± 2	99 ± 1	100 –	99 –	100 –	92 ± 15

Numbers are averages of four replications with one bolt/replicate. Values shown are: 100 – (treated/control × 100).

Table 14.—Average number of SPB trapped per month in the preventive study for each of four treatments and eight test sites in Mississippi during 1978–79

Site	Control	Lindane	1% fenitrothion	2% fenitrothion
13	59	88	132	127
14	26[a]	125	33	69
15	96	157	278	141
16	120	370[b] (5)	454[c] (2)	415
17	272	403	555[c] (1)	274[d] (2)
18	264	241	191[c] (2)	269
19	83	396	266[c] (3,6,4)	223
20	39[a]	92	59	168

[a]All control trees dead with the exception of three in site 14 and one in site 20; average time until death was 2.8 months.
[b]Only one tree dead; time until death was 9 months.
[c]Ten trees dead; average time until death was 7.8 months.
[d]Only one tree dead; time until death was 8 months.

Numbers in parentheses are month of highest SPB trap count on individual trees which died after insecticide treatment.

Table 15.—Comparison of hanging-bolt and standing-tree techniques for measuring preventive control of SPB by two insecticides, Mississippi, by number of months after treatment

Treatment	Trap counts		Activity in bolt bark samples	
	Bolt $\bar{X} \pm SE$	Standing tree $\bar{X} \pm SE$	Successful attacks/bolt $\bar{X} \pm SE$	Length of egg gallery (cm) $\bar{X} \pm SE$
		Zero month		
1% fenitrothion	46 ± 4	32 ± 5	10 ± 2 b	4 ± 4 b
2% fenitrothion	150 ± 34	35 ± 6	4 ± .5 b	0 b
Lindane	54 ± 18	8 ± 2	4 ± 2 b	0 b
Control	67 ± 28	10 ± 2	74 ± 17 a	230 ± 32 a
		Four months		
1% fenitrothion	55 ± 2	39 ± 6	14 ± 4 a	145 ± 2 b
2% fenitrothion	97 ± 37	136 ± 30	6 ± 1 b	45 ± 23 c
Lindane	139 ± 33	449 ± 211	2 ± 1 b	29 ± 9 c
Control	44 ± 33	Terminated	13 ± 4 a	203 ± 9 a
		Ten months		
1% fenitrothion	26 ± 8	27 ± 8	15 ± 2 b	292 ± 5 b
2% fenitrothion	43 ± 6	13 ± 3	10 ± 3 b	161 ± 20 c
Lindane	21 ± 5	22 ± 3	12 ± 5 b	85 ± 33 d
Control	32 ± 5	Terminated	42 ± 6 a	347 ± 15 a

Means followed by the same letter do not differ significantly ($P > 0.05$) in Duncan's new multiple range test.

Table 16.–Remedial control of SPB by two insecticides in Georgia and South Carolina

Treatment	Average number SPB per bolt/1,000 cm²			Average % mortality			Average emergence per bolt
	Larvae	Pupae	Adult	Larvae	Pupae	Adult	
Control	51 ± 54	13 ± 15	17 ± 12	18 ± 37	39 ± 42	17 ± 15	123 ± 89
0.5% lindane	49 ± 85	6 ± 9	29 ± 17	8 ± 9	40 ± 56	69 ± 60	19 ± 4
0.5% chlorpyrifos	92 ± 71	36 ± 38	26 ± 13	12 ± 11	27 ± 27	47 ± 57	127 ± 11
1% chlorphyrifos	54 ± 75	9 ± 13	27 ± 19	15 ± 19	48 ± 77	71 ± 76	24 ± 8
2% chlorpyrifos	22 ± 46	6 ± 10	38 ± 16	29 ± 33	62 ± 95	73 ± 26	31 ± 10

Numbers are averages of 14 replications ± 1 SD.

Table 17.–Emergence and survival of SPB from bolts treated with remedial insecticides in August and November, 1978, Georgia

Treatment and replicate	Total SPB emergence	Mean daily emergence	Survival (hours after emergence)		
			24	48	72
	... Number ...		*..... Percent .....*		
		August 1978			
Check:					
1	491	6.6	90.3	86.3	88.5
2	1,056	25.1	98	95.7	91
3	455	10.8	90.5	88	78
4	457	10.9	97	94.3	92.5
Lindane:					
1	83	2	54	34.5	7.5
2	35	.87	90	57.7	25
3	43	1.03	36.5	13	0
4	55	1.3	81	50	30
1% fenitrothion:					
1	78	1.83	10	8.5	0
2	14	.33	3.5	3.5	0
3	35	.8	7.5	14	0
4	37	.87	24.5	7	0
2% fenitrothion:					
1	53	1.27	5	7	0
2	43	1.03	24.5	3.5	0
3	38	.9	6.5	0	–
4	49	1.17	.5	0	–
		November 1978			
Check:					
1	910	21.66 ± 32	96	86	77
2	235	5.57 ± 8	98	89	83
3	244	5.98 ± 15	94	88	80
4	165	3.93 ± 6	93	81	74
Lindane:					
1	22	.53 ± .9	32	12	4
2	20	.47 ± 1	32	14	9
3	28	.69 ± 2	14	9	1
4	4	.067 ± 0.5	100	100	100
1% fenitrothion:					
1	1	.027 ± 0.15	0	–	–
2	0	0	–	–	–
3	320	8.27 ± 12	1	.1	1
4	183	4.33 ± 7	19	19	18
2% fenitrothion:					
1	10	.28 ± 0.53	11	–	–
2	4	.067 ± 0.62	0	–	–
3	23	.53 ± 1.6	0	–	–
4	69	1.67 ± 3	19	7	7

Table 18.—Emergence and percent survival of SPB from infested test bolts treated with two insecticides, Mississippi

Treatment	Emergence		$\bar{X} \pm SE$		
	$\bar{X} \pm SE$[a]	Total	Alive at collection (0–24 hours)[b]	Survival after 24 hours (24 –48 hours)[c]	Survival after 48 hours (48–72 hours)
			Percent		
		First 14 days			
Control	249 ± 65	(7,470)	19.4 ± 4.6	3.9 ± 3.6	0
Lindane	164 ± 94	(997)	9.2 ± 4.1	.5 ± .3	0
1% fenitrothion	695 ± 583	(2,084)	7.0 ± 5.0	.4 ± .4	0
		Next 17 days			
Control	176 ± 122	(527)	36.5 ± 12.3	18 ± 18	0
Lindane	187 ± 115	(561)	16.8 ± 1.9	2.4 ± 1.4	0
1% fenitrothion	247 ± 139	(772)	9.1 ± 3.0	1.7 ± 1.7	0
2% fenitrothion	292 ± 238	(876)	8.5 ± 6.3	.1 ± 0.1	0

[a]Three replications for a total of nine trees per treatment, three 0.5-m bolts/tree.
[b]% survival is average of number alive ÷ total emerged/replication.
[c]24-hour error possible due to only one check/day.

Table 19.—Number of SPB before treatment and after emergence from bolts treated with chlorpyrifos, compared with lindane, Louisiana

Treatment	Total No. of emerging beetles	Avg. No. of brood/ 0.09 m^2 before treatment	Avg. No. of emerging beetles/ 0.09 m^2	% beetles emerging from treatments
Control	9,885	196	125	64
Lindane	2,309	256	29	11
Chlorpyrifos:				
2%	1,565	263	21	8
1%	1,719	298	24	8
0.5%	3,275	221	46	21

Table 20.—Effect of simulated rain on loss of lindane and chlorpyrifos-methyl from pine bark

Treatment and wash time after application	Gallons water/0.09 m^2 of bark used as wash	% loss based on nonwashed controls
0.5% lindane (EC),		
10 minutes	0.33	17
10 minutes	1.67	26
2 hours	.33	0
2 hours	1.67	3
0.5% lindane (WP),		
10 minutes	.33	30
10 minutes	1.67	51
2 hours	.33	0
2 hours	1.67	22
1% chlorpyrifos-methyl (EC),		
10 minutes	.33	36
10 minutes	1.67	58
2 hours	.33	34
2 hours	1.67	46

Table 21.—Schedule for collecting cloth residue samples through surface contact with chlorpyrifos-treated bark

Treatment	No. of replications	
	1-unit area[a]	3-unit area[a]
0.5% wet	2	2
0.5% dry	2	2
1% wet	4	4
1% dry	4	4
2% wet	4	4
2% dry	4	4
Control	3	3

[a]Unit area represents 1 ft² (0.09 m²) surface area contacted.

Wet—immediately after treatment when bark is still wet; Dry—approximately 2 hours after treatment when bark has dried.

Table 22.—Persistence of insecticides on bark of standing loblolly pines

Treatment	Initial concentration	Months after treatment							
		1	2	4	6	8	10	12	15
	p/m	..... *Percent of initial concentration*							
Lindane:									
0.5%	745 ± 266[a]	46 ± 10	28 ± 9	9 ± 4	5 ± 3	8 ± 7	5 ± 5	5 ± 4	6 ± 2
Chlorpyrifos:									
1%	1,449 ± 574	50 ± 3	58 ± 31	46 ± 20	37 ± 12	32 ± 14	32 ± 16	29 ± 14	18 ± 13
2%	3,192 ± 1,110	50 ± 6	59 ± 23	44 ± 17	33 ± 8	28 ± 13	26 ± 10	22 ± 9	14 ± 2
Chlorpyrifos-methyl:									
1%	2,374 ± 431	–	47 ± 10	31 ± 6	22 ± 5	19 ± 7	19 ± 7	13 ± 1	9 ± 2
2%	4,738 ± 824	–	43 ± 8	28 ± 9	28 ± 2	17 ± 7	27 ± 6	11 ± 5	8 ± 2

[a]± 1 SD.

Numbers represent the average of treatments made in 1975 and 1976 with four replications of one tree/replicate.

Table 23.—Residue levels of insecticides at indicated times after treatment

Treatment	0-day	2 months	4 months	6 months	8 months	10 months
	..... *p/m*					
Lindane	2,521	382 (15)	107 (4)	71 (3)	79 (3)	58 (2)
1% fenitrothion	3,474	1,360 (39)	984 (28)	870 (25)	738 (21)	758 (22)
2% fenitrothion	7,050	3,305 (47)	2,203 (31)	1,802 (26)	1,280 (18)	1,475 (21)
2% carbaryl (UCSF-2)	3,608	–	–	794 (22)	<5	–
2% carbaryl (UCSF-2)[a]	4,169	2,022 (48)	–	–	–	–
2% carbaryl (Sevimol 4®)[a]	3,227	1,525 (47)	1,292 (40)	<5	–	–

[a]Replicates applied 2 months after initial carbaryl application.

Numbers in parentheses are percentages of 0-day concentration.

Table 24.–Effect of adjuvants on persistence of insecticides on bark of loblolly pines at indicated times

Insecticide and adjuvant	2 months	4 months	6 months	9 months
		Percent of initial concentration		
5% lindane:				
+ Exhalt®	31 ± 3	12 ± 2	9 ± 1	9 ± 1
+ Nu-Film 17®	37 ± 8	16 ± 3	10 ± 1	7 ± 2
+ Plant Gard®	39 ± 2	16 ± 2	12 ± 2	7 ± 2
+ Plyac®	36 ± 15	25 ± 12	20 ± 2	15 ± 0
+ Stretcher®	34 ± 5	16 ± 3	15 ± 2	8 ± 2
+ Triton®	28 ± 8	16 ± 9	11 ± 1	4 ± 0
- Control	34 ± 0	10 ± 1	9 ± 1	8 ± 2
1% chlorpyrifos:				
+ Exhalt®	49 ± 3	43 ± 17	40 ± 18	22 ± 6
+ Nu-Film 17®	66 ± 17	42 ± 19	37 ± 12	31 ± 7
+ Plant Gard®	51 ± 10	25 ± 2	24 ± 1	23 ± 11
+ Plyac®	45 ± 11	37 ± 12	29 ± 4	22 ± 2
+ Stretcher®	67 ± 12	37 ± 8	33 ± 8	21 ± 2
+ Triton®	73 ± 9	45 ± 2	40 ± 1	29 ± 1
- Control	65 ± 18	34 ± 15	31 ± 5	24 ± 1

Numbers are averages of three replications with one tree/replicate.

Table 25.–Comparative distribution of lindane downwind from each of three spray-delivery systems

Distance from source (meters)	John Bean	Delavan foam	Accutrol foam
		μg lindane/cm²	
5	0.02	0.08	0.04
10	11.03	0.59	0.07
15	6.75 ± 8.75	13.03 ± 8.54	12.33 ± 12.16
20	10.23 ± 10.11	6.11 ± 7.18	11.66 ± 16.25
25	5.22 ± 3.22	.50 ± 0.36	.35 ± 0.30
30	.78 ± 0.65	.15 ± 0.12	.10 ± 0.10
35	.11 ± 0.03	.27 ± 0.14	.06 ± 0.05
40	.07 ± 0.04	.22 ± 0.24	.03 ± 0.02
45	.04 ± 0.003	.01 ± 0.01	.15 ± 0.13
50	.01 ± 0.0004	.01 ± 0.01	.01 ± 0.003

Numbers are averages of three replications ± 1 SD for distances from 15 through 40 m, one replication for 5 and 10 m, and two replications for 45 and 50 m.

Table 26.—Cloth residue analysis for chlorpyrifos

Treatment	Louisiana		Georgia	
	Wet	Dry	Wet	Dry
	..... *mg/0.09 m²*			
2 percent:				
(1)	53.2	1.7	65.7	9.9
(3)	27.3	1.0	59.8	9.6
1 percent:				
(1)	16.4	1.8	27.3	4.0
(3)	10.2	1.4	13.1	2.7
0.5 percent:[a]				
(1)	3.6	.9	–	–
(3)	1.9	.5	–	–

[a]Averages based on two replications.

Wet samples rubbed 5 minutes after spraying; dry samples, 2 hours after spraying.

Numbers in parentheses represent units of area (0.09 m²) of bark rubbed with cloth. Residue is reported as 0.09 m²; therefore, residue for three units rubbed is not total mg of residue in cloth sample.

Table 27.—Characteristics of soils in studies on effect of chlorpyrifos and fenitrothion on soil microbial populations

Soil No.	Carbon	Organic matter	Total nitrogen
	..... *Percent*		*p/m*
1	4.26	7.33	1,440
2	1.04	1.78	4,339
3	1.14	1.97	435
4	1.03	1.77	419
5	.77	1.33	339
6	1.84	3.16	704

Table 28.—Effect of fenitrothion on soil microbial populations

Soil No.	Mean ± SD				
	0 p/m	1 p/m	10 p/m	50 p/m	100 p/m
	Mean No. of fungal propagules/g soil × 10^2 (average of 10 replicates)				
2	708bc ± 251	968ab ± 458	1,072a ± 485	735bc ± 132	642c ± 112
3	1,317a ± 460	1,135a ± 385	995a ± 648	1,302a ± 278	1,070a ± 558
4	642a ±328	515ab ± 228	570ab ± 305	505ab ± 110	335b ± 165
5	428a ± 128	588a ± 200	507a ± 248	505a ± 240	590a ± 278
6	322c ± 205	562b ± 238	792a ± 232	910a ± 202	800a ± 165
Average	682a ± 388	752a ± 280	788a ± 250	792a ± 332	692a ± 265
	Mean No. of bacteria/g soil × 10^3 (average of 12 replicates)				
1	410b ± 198	407b ± 205	655ab ± 252	745a ± 505	448b ± 185
2	795a ± 722	442a ± 318	448a ± 355	935a ± 1,448	637a ± 438
3	758ab ± 488	1,182a ± 752	440b ± 265	670b ± 318	795ab ± 370
5	95b ± 88	238ab ± 155	132b ± 102	132b ± 57	380a ± 280
6	162b ± 58	148b ± 62	230ab ± 185	305a ± 242	155b ± 110
Average	445a ± 325	484a ± 409	381a ± 205	558a ± 330	483a ± 245

For each soil, numbers with the same letters are not significantly different in Duncan's multiple range test ($P = 0.05$).

Table 29.—Effect of chlorpyrifos on soil microbial populations

Soil No.	Mean ± SD				
	0 p/m	1 p/m	10 p/m	50 p/m	100 p/m
	Mean No. of fungal propagules/g soil × 10^2 (average of 15 replicates)				
2	1,120a ± 468	628b ± 260	475bc ± 188	435bc ± 165	238c ± 98
3	1,282a ± 198	1,448a ± 419	1,718a ± 642	1,390a ± 542	1,410a ± 518
5	430ab ± 250	540ab ± 320	318b ± 182	610a ± 385	400ab ± 260
Average	544a ± 453	872a ± 500	837a ± 767	812a ± 508	682a ± 635
	Mean No. of bacteria/g soil × 10^3 (average of 15 replicates)				
2	531b ± 344	1,197a ± 492	581ab ± 518	556b ± 387	481b ± 266
3	538a ± 466	506a ± 441	697a ± 380	581a ± 380	306a ± 294
4	219ab ± 107	106b ± 40	216ab ± 90	409a ± 343	338a ± 247
Average	420a ± 175	602a ± 552	560a ± 302	518a ± 92	375a ± 92

For each soil, numbers with the same letters are not significantly different in Duncan's multiple range test ($P = 0.05$).

Table 30.—Effect of insecticides on mean numbers of soil fungal propagules/g through time

Insecticide and concentration (p/m)	Days of incubation		
	1	7	14
	Hundreds of propagules[a]		
Fenitrothion:			
0	675 b	1,160 a	1,410 ab
1	730 b	1,160 a	1,100 bc
10	810 b	1,020 a	1,910 a
50	805 b	1,005 a	750 c
100	1,105 a	885 a	645 c
Chlorpyrifos:			
0	1,015 d	965 de	1,380 d
1	1,360 d	750 ef	1,275 d
10	1,109 d	1,130 d	1,420 d
50	1,095 d	495 f	1,170 d
100	1,015 d	730 ef	930 d

[a]Each value is the average of five replicates.

Numbers with the same letter do not differ significantly according to Duncan's multiple range test ($P = 0.05$).

Table 31.—Radioactivity from chlorpyrifos-treated soil fungus cultures after indicated times of incubation

Fungus	7 days		14 days		28 days	
	Organic	Aqueous	Organic	Aqueous	Organic	Aqueous
	Percent					
Control	89 (61)	11 (8)	81 (23)	19 (5)	73 (22)	27 (8)
Trichoderma harzianum	85 (58)	15 (10)	76 (27)	24 (9)	83 (4)	17 (1)
Penicillium multicolor	79 (49)	21 (13)	84 (30)	16 (6)	54 (2)	46 (1)
P. vermiculatum	84 (54)	16 (10)	73 (29)	27 (11)	50 (5)	50 (5)
Mucor sp.	76 (51)	24 (16)	68 (10)	32 (5)	20 (4)	80 (14)

Numbers are the average of three replicates. Those outside the parentheses are based on recovered radioactivity. Those inside parentheses are based on initial radioactivity.

Table 32.—Effects of lindane and chlorpyrifos-methyl on litter mesofauna

Time and treatment	Organisms						
	Orbatid	Mesostigmatid	Trombidiform	Collembolan	Others	Total mites	Total
	No./20 cm² litter area[a]						
Before treatment:							
0.5% lindane	104	2	68	16	2	174	192
0.5% chlorpyrifos-methyl	128	2	78	23	2	208	233
1% chlorpyrifos-methyl	191	6	183	26	4	380	410
Control	135	5	146	26	4	336	366
1 week after treatment:							
0.5% lindane	55	1.1	41*	3.9	0.6*	105*	110*
0.5% chlorpyrifos-methyl	67	1.1	40*	4.6	.5*	115*	120*
1% chlorpyrifos-methyl	102*S	1.5	58*	4.4	1.1*	154*	159*
Control	52	1.3	241	7.9	2.4	285	296
6 weeks after treatment:							
0.5% lindane	130	5.8	73*S	13*	2.2	225	241
0.5% chlorpyrifos-methyl	125	1.7*	43	11*	2.4	185	197
1% chlorpyrifos-methyl	164	5.3	50	17*	2.0	209	228
Control	152	7.2	33	32	3.2	172	207
23 weeks after treatment:							
0.5% lindane	136	7.5	25	9.7*	3.4	168	182
0.5% chlorpyrifos-methyl	145	4.1	19	6.5*	.6*	171	178
1% chlorpyrifos-methyl	164	4.2	25	7.0*	1.7*	201	208
Control	121	4.9	32	27	4.2	148	179
75 weeks after treatment:							
0.5% lindane	109*S	5.7	24	19	5.1*S	139*S	163*S
0.5% chlorpyrifos-methyl	97*S	6	20	9.8*	1.1*	125	136
1% chlorpyrifos-methyl	100*S	4.6*	31*S	9.1*	2.9	137*S	148
Control	65	7.9	23	18	3.0	94	115

[a]Means are adjusted for covariates (pretreatment counts and moisture content) for an average of 30 samples.

*Significantly different from control ($P = 0.05$), S indicates stimulation using Dunnett's test comparing each treatment effect with control.

Table 33.—Effects of lindane and chlorpyrifos-methyl on soil mesofauna

Time and treatment	Organisms						
	Orbatid	Mesostigmatid	Trombidiform	Collembolan	Others	Total mites	Total
	No./20 cm² soil area[a]						
Before treatment:							
0.5% lindane	109	2	43	38	4	154	196
0.5% chlorpyrifos-methyl	66	1	66	36	3	133	172
1% chlorpyrifos-methyl	82	2	40	32	2	124	158
Control	44	1	16	20	1	61	82
1 week after treatment:							
0.5% lindane	43	1.2	27	16	2.5	72	90
0.5% chlorpyrifos-methyl	73	1.1	29	23	2.2	99	124
1% chlorpyrifos-methyl	76	1.1	18	23	2.2	96	121
Control	59	1.2	23	17	1.7	87	106
6 weeks after treatment:							
0.5% lindane	49	1.5*	15	11*	3.1	66	82
0.5% chlorpyrifos-methyl	40	1.7*	23*S	12*	2.6	61	76
1% chlorpyrifos-methyl	34	1.2*	16	19	1.4	52	72
Control	47	2.8	11	21	1.9	64	83
23 weeks after treatment:							
0.5% lindane	71*S	3.7*S	12	9.4*	2.2*	82	95
0.5% chlorpyrifos-methyl	56	5.6*S	17	11*	1.1*	79	92
1% chlorpyrifos-methyl	40	3.0	9	9.5*	1.1*	51	61
Control	41	1.3	14	16	12	61	88
75 weeks after treatment:							
0.5% lindane	54*S	1.4	8.2	5.9	1.9	63	72
0.5% chlorpyrifos-methyl	60*S	1.0	12	7.8	1.5	72*S	82*S
1% chlorpyrifos-methyl	46	1.2	12	10	1.7	60	72
Control	32	.9	6.3	9.0	1.3	40	48

[a]Means are adjusted for covariates (pretreatment counts and moisture content) for an average of 30 samples.

*Significantly different from control ($P = 0.05$); S indicates stimulation using Dunnett's test comparing each treatment effect with control.

Table 34.–Insecticide residues in soil and litter mesofauna tests

Time after spraying and treatment	Litter			Soil		
	Mean ± SD	Median	Range	Mean ± SD	Median	Range
	..... *p/m*					
1 day:[a]						
0.5% lindane	9.4 ± 9.6	7.6	19.0	–	–	–
0.5% chlorpyrifos-methyl	21.1 ± 29.9	5.0	52.8	–	–	–
1% chlorpyrifos-methyl	14.8 ± 9.8	10.3	18.1	–	–	–
1 week:[b]						
0.5% lindane	8.8 ± 7.9	4.4	28.4	0.16 ± 0.07	0.1	0.16
0.5% chlorpyrifos-methyl	30.1 ± 21.1	21.0	66.3	3.05 ± 2.75	2.38	8.1
1% chlorpyrifos-methyl	33.9 ± 32.5	18.0	115.4	4.41 ± 1.88	3.79	6.1
5 months:						
0.5% lindane	2.02 ± 2.93	.6	11.0	<0.1	–	–
0.5% chlorpyrifos-methyl	8.06 ± 21.7	.6	85.4	<0.1	–	–
1% chlorpyrifos-methyl	.98 ± 1.02	.6	3.24	<0.1	–	–

[a] Average of three replicates.

[b] Average of 15 replicates in litter and 10 replicates in soil.

Table 35.—Efficacy of partial tree-bole sprays

Spray coverage	Number of trees		
	Treated	Attacked	Killed
		Spray applied during 1979[a]	
Full bole	16	2	1[b]
Below 6.5 m	16	15	15
Below 2.0 m	12	12	12
Unsprayed check	12	12	12
		Spray applied during 1980[c]	
Full bole	5	0	0
Above 5 m	23	2	1
Below 5 m	7	7	7
Unsprayed check	11	11	11

[a]Trees were 20 m in height; half were sprayed with 2% chlorpyrifos, half with 0.5% lindane.
[b]Residue analysis indicated this tree was not sprayed.
[c]Trees were 17 m in height; all were sprayed with 0.5% lindane.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Hastings, Felton L., and Jack E. Coster, eds.
1981. Field and laboratory evaluations of insecticides for southern pine beetle control. USDA For. Serv., Gen. Tech. Rep. SE-21, 40 p. Southeast. For. Exp. Stn., Asheville, N.C.

Reports results of laboratory screenings and field studies of insecticides for use against the southern pine beetle. Preventive as well as remedial efficacy were observed, along with phytotoxicity to pine and understory hardwood species, effects of insecticides on soil microbial and mesofaunal populations, and degradation of insecticides by selected soil microbes.

KEYWORDS: *Dendroctonus frontalis*, efficacy, microbial degradation, phytotoxicity, adjuvants, lindane, chlorpyrifos, chlorpyrifos-methyl, fenitrothion.

Hastings, Felton L., and Jack E. Coster, eds.
1981. Field and laboratory evaluations of insecticides for southern pine beetle control. USDA For. Serv., Gen. Tech. Rep. SE-21, 40 p. Southeast. For. Exp. Stn., Asheville, N.C.

Reports results of laboratory screenings and field studies of insecticides for use against the southern pine beetle. Preventive as well as remedial efficacy were observed, along with phytotoxicity to pine and understory hardwood species, effects of insecticides on soil microbial and mesofaunal populations, and degradation of insecticides by selected soil microbes.

KEYWORDS: *Dendroctonus frontalis*, efficacy, microbial degradation, phytotoxicity, adjuvants, lindane, chlorpyrifos, chlorpyrifos-methyl, fenitrothion.

The Forest Service, U.S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.